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(72) Inventors:

- Kato, Takatoshi, Yokohama Works
Yokohama-shi, Kanagawa 244-8588 (JP)
- Sasaoka, Elsuke, Yokohama Works
Yokohama-shi, Kanagawa 244-8588 (JP)
- Tanaka, Shigeru, Yokohama Works
Yokohama-shi, Kanagawa 244-8588 (JP)

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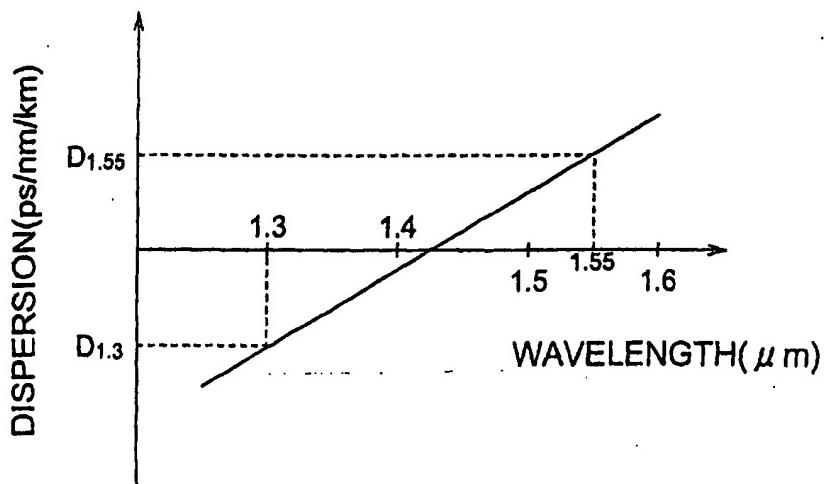
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(74) Representative: HOFFMANN - EITLE
Patent- und Rechtsanwälte
Arabellastrasse 4
81925 München (DE)(71) Applicant: Sumitomo Electric Industries, Ltd.
Osaka-shi, Osaka 541-0041 (JP)**(54) OPTICAL FIBER AND OPTICAL TRANSMISSION SYSTEM INCLUDING THE SAME**

(57) The present invention relates to an optical fiber which enables favorable optical communications in 1.3- μ m and 1.55- μ m wavelength bands, and an optical transmission system including the same. The optical fiber according to the present invention has only one zero-dispersion wavelength within a wavelength range of

1.20 μ m to 1.60 μ m, the zero-dispersion wavelength existing within a wavelength range of 1.37 μ m to 1.50 μ m, and has a positive dispersion slope at the zero-dispersion wavelength, thereby enabling favorable optical communications utilizing each signal light in the 1.3- μ m and 1.55- μ m wavelength bands sandwiching the zero-dispersion wavelength.

Fig. 1B

Description**Technical Field**

- 5 [0001] The present invention relates to an optical fiber applicable to a transmission line in optical communications, and an optical transmission system including this optical fiber.

Background Art

- 10 [0002] Conventionally, as a transmission line in optical communications, standard single-mode optical fibers having a zero-dispersion wavelength in a 1.3- μm wavelength band (1280 nm to 1320 nm) have mainly been utilized. The transmission loss resulting from the main material (silica) of such an optical fiber has been known to become the lowest in a 1.55- μm wavelength band (1530 nm to 1565 nm). In addition, optical fiber amplifiers using an Er-doped optical fiber can amplify light in the 1.55- μm wavelength band at a high efficiency. For such a reason, dispersion-shifted optical fibers designed so as to have a zero-dispersion wavelength in the 1.55- μm wavelength band are applied to transmission lines in wavelength division multiplexing (WDM) communications for transmitting a plurality of wavelengths of signal light. As for a light source for sending out signal light, device technologies for enabling light in the 1.3- μm wavelength band and light in the 1.55- μm wavelength band to be outputted have conventionally been established.

Disclosure of the Invention

- 20 [0003] The inventors have studied the prior art mentioned above and, as a result, found problems as follows. Namely, in the case where light in the 1.3- μm wavelength band is transmitted while a dispersion-shifted optical fiber having a zero-dispersion wavelength in the 1.55- μm wavelength band is used as an optical transmission line, the absolute value of dispersion becomes so large that WDM communications cannot be carried out in a wide band. Also, when signal light in the 1.55- μm wavelength band is transmitted through such a dispersion-shifted optical fiber, the absolute value of dispersion becomes so small that four-wave mixing, which is one of nonlinear optical phenomena, is likely to occur. In the case where light in the 1.3- μm wavelength band is transmitted while a standard single-mode optical fiber having a zero-dispersion wavelength in the 1.3- μm wavelength band is used as an optical transmission line, on the other hand,
- 25 30 the absolute value of dispersion becomes so small that four-wave mixing, which is one of nonlinear optical phenomena, is likely to occur. Also, when signal light in the 1.55- μm wavelength band is transmitted through such a single-mode optical fiber, the absolute value of dispersion becomes so large that WDM communications cannot be carried out in a wide band.

- 35 [0004] For this matter, attempts have been made to develop optical fibers for suppressing the occurrence of dispersion over a wide wavelength band (see, for example, K. Okamoto et al., "Zero total in single-mode optical fibers over an extended spectral range," Radio Science, Volume 17, Number 1, pages 31-36, January-February 1982). For example, an optical fiber having a low dispersion value over a wide wavelength band has been proposed by yielding a large relative refractive index difference of 2.4% between its cladding region and core region and a small diameter of 3.5 μm in the core region. However, it is difficult to make such an optical fiber having a very large relative refractive index difference between the cladding region and core region, and its transmission loss is large. In an optical fiber whose core region has a smaller diameter, on the other hand, the effective area becomes smaller, and nonlinear optical phenomena are likely to occur.

- 40 [0005] In order to overcome problems such as those mentioned above, it is an object of the present invention to provide an optical fiber which enables efficient transmission of both of signal light in the 1.3- μm wavelength band and signal light in the 1.55- μm wavelength band, and an optical transmission system including the same.

- 45 [0006] The optical fiber according to the present invention is an optical fiber which enables efficient transmission of both of signal light in the 1.3- μm wavelength band and signal light in the 1.55- μm wavelength band, the optical fiber having only one zero-dispersion wavelength within a wavelength range of 1.20 μm to 1.60 μm and having a positive dispersion slope at the zero-dispersion wavelength. Here, this zero-dispersion wavelength lies within a wavelength range of 1.37 μm to 1.50 μm sandwiched between the 1.3- μm wavelength band and the 1.55- μm wavelength band. Also, the above-mentioned dispersion slope preferably has an absolute value of 0.10 ps/nm²/km or less at the above-mentioned zero-dispersion wavelength (preferably 0.06 ps/nm²/km or less at a wavelength of 1.55 μm), and monotonously changes (e.g., monotonously increases) at least in a wavelength range of 1.30 μm to 1.55 μm .

- 50 [0007] Thus, since this optical fiber has a zero-dispersion wavelength within the wavelength range of 1.37 μm to 1.50 μm including a wavelength of 1.38 μm at which an increase in transmission loss caused by OH absorption is seen, dispersion occurs to a certain extent in the vicinity of the 1.3- μm wavelength band and in the vicinity of the 1.55- μm wavelength band. As a consequence, the optical fiber comprises a structure in which four-wave mixing is hard to occur even when the signal light in the 1.3- μm wavelength band and the signal light in the 1.55- μm wavelength band prop-

agate therethrough.

[0008] In the case where a thulium-doped fiber amplifier having an amplification band in a 1.47- μm wavelength band is utilized, the zero-dispersion wavelength is more preferably set within a wavelength range of 1.37 μm to 1.43 μm . It is because of the fact that the transmission band can further be widened if the zero-dispersion wavelength is aligned with a skirt of the OH absorption peak (1.38 μm). In the case where the above-mentioned OH absorption peak is kept low by dehydration processing or the like, so as to utilize the wavelength band including the wavelength of 1.38 μm as its signal light wavelength band, on the other hand, the zero-dispersion wavelength may be set within a wavelength range of longer than 1.45 μm but not longer than 1.50 μm in order to intentionally generate dispersion in the above-mentioned wavelength band.

[0009] In the optical fiber, while the dispersion slope monotonously increases, the absolute value of the dispersion slope at its zero-dispersion wavelength is 0.10 ps/nm²/km or less, and the dispersion slope at a wavelength of 1.55 μm is preferably 0.06 ps/nm²/km or less, whereby the dispersion in the 1.3- μm wavelength band and the dispersion in the 1.55- μm wavelength band are homogenized. Here, each of the absolute value of dispersion in the 1.3- μm wavelength band and the absolute value of dispersion in the 1.55- μm wavelength band is 6 ps/nm/km or more but 12 ps/nm/km or less.

[0010] As mentioned above, the optical fiber according to the present invention realizes efficient optical communications in both of the 1.3- μm wavelength band and the 1.55- μm wavelength band. From the viewpoint of guaranteeing a single mode, the case where the cutoff wavelength is 1.3 μm or shorter while the transmission line length is several hundreds of meters or less is preferable since only the ground-mode light can propagate in each of the 1.3- μm wavelength band and the 1.55- μm wavelength band. Also, in view of the dependence of cutoff wavelength on distance, no practical problem occurs in optical transmission over a relatively long distance (a transmission line length of several kilometers or less) even if the cutoff wavelength is 1.45 μm or shorter (in the case where it is longer than the signal light wavelength). From the viewpoint of reducing the bending loss, on the other hand, there are cases where the bending loss increases remarkably when the cutoff wavelength is shorter than 1.0 μm . As a consequence, the cutoff wavelength is preferably 1.05 μm or more, more preferably 1.30 μm or more.

[0011] Further, in order to enable efficient optical transmission in the 1.3- μm wavelength band and 1.55- μm wavelength band, the optical fiber according to the present invention has a bending loss which becomes 0.5 dB or less, preferably 0.06 dB or less, per turn when wound at a diameter of 32 mm at a wavelength of 1.55 μm , and has an effective area A_{eff} which becomes 45 μm^2 or more, preferably greater than 49 μm^2 at a wavelength of 1.55 μm . Also, the amount of increase in transmission loss caused by OH absorption at a wavelength of 1.38 μm in the optical fiber is 0.1 dB/km or less. In particular, if the amount of increase in transmission loss caused by OH absorption at a wavelength of 1.38 μm is 0.1 dB/km or less, then a wavelength band in the vicinity of this wavelength of 1.38 μm can be utilized for a signal light wavelength band. In this case, in order to intentionally generate dispersion in the wavelength band in the vicinity of the wavelength of 1.38 μm (in order to suppress four-wave mixing), the zero-dispersion wavelength may be set within a wavelength range of longer than 1.45 μm but not longer than 1.50 μm .

[0012] Here, the effective area A_{eff} is given, as shown in Japanese Patent Application Laid-Open No. HEI 8-248251 (EP 0 724 171 A2), by the following expression (1):

$$A_{\text{eff}} = 2\pi \left(\int_0^{\infty} E^2 r dr \right)^2 / \left(\int_0^{\infty} E^4 r dr \right) \quad (1)$$

where E is the electric field accompanying the propagated light, and r is the radial distance from the core center.

[0013] The optical fiber according to the present invention has a refractive index profile in which the maximum and minimum values of relative refractive index difference with reference to the refractive index of pure silica (silica which is not intentionally doped with impurities) are 1% or less and -0.5% or more, respectively. In such a refractive index profile, the relative refractive index difference of a high refractive index region doped with Ge element, for example, with respect to pure silica is 1% or less, whereas the relative refractive index difference of a low refractive index region doped with F element, for example, with respect to pure silica is -0.5% or more, whereby its manufacture (refractive index control by doping with impurities) is easy, and the transmission loss can be lowered. Here, the minimum value of relative refractive index difference with reference to the refractive index of pure silica is preferably -0.2% or more, more preferably greater than -0.15% from the viewpoint of facilitating the manufacture of the optical fiber.

[0014] The optical fiber having various characteristics such as those mentioned above can be realized by various configurations. Namely, a first configuration of the optical fiber can be realized by a structure comprising a core region which extends along a predetermined axis and has a predetermined refractive index, and a cladding region provided on the outer periphery of the core region. The optical fiber of the first configuration may further comprise a depressed

cladding structure. The depressed cladding structure is realized when the above-mentioned cladding region is constituted by an inner cladding, provided on the outer periphery of the core region, having a lower refractive index than the core region; and an outer cladding, provided on the outer periphery of the inner cladding, having a refractive index higher than that of the inner cladding but lower than that of the core region.

5 [0015] As with the first configuration, a second configuration of the optical fiber comprises a core region and a cladding region provided on the outer periphery of the core region. However, the core region is constituted by a first core having a predetermined refractive index; and a second core, provided on the outer periphery of the first core, having a lower refractive index than the first core. In the case where the optical fiber of the second configuration comprises a depressed cladding structure, the cladding region is constituted by an inner cladding, in contact with the outer periphery of the 10 second core, having a lower refractive index than the second core; and an outer cladding, provided on the outer periphery of the inner cladding, having a refractive index higher than that of the inner cladding but lower than that of the second core.

15 [0016] As with the first configuration, a third configuration of the optical fiber comprises a core region extending along a predetermined axis and a cladding region provided on the outer periphery of the core region. In particular, the core region comprises a first core having a predetermined refractive index; a second core, provided on the outer periphery of the first core, having a lower refractive index than the first core; and a third core, provided on the outer periphery of the second core, having a higher refractive index than the second core. In the case where the optical fiber of the third 20 configuration comprises a depressed cladding structure, the cladding region is constituted by an inner cladding, in contact with the outer periphery of the third core, having a lower refractive index than the third core; and an outer cladding, provided on the outer periphery of the inner cladding, having a refractive index higher than that of the inner cladding but lower than that of the third core.

25 [0017] When the third configuration mentioned above is employed, it becomes easier to obtain an optical fiber having a low dispersion slope of 0.06 ps/nm²/km or less at a wavelength of 1.55 μm in particular.

30 [0018] Further, a fourth configuration of the optical fiber also comprises a core region extending along a predetermined axis and a cladding region provided on the outer periphery of the core region. In particular, the core region comprises a first core having a predetermined refractive index; a second core, provided on the outer periphery of the first core, having a higher refractive index than the first core. In the case where the optical fiber of the fourth configuration comprises a depressed cladding structure, the cladding region is constituted by an inner cladding, in contact with the outer periphery of the second core, having a lower refractive index than the second core; and an outer cladding, provided 35 on the outer periphery of the inner cladding, having a refractive index higher than that of the inner cladding but lower than that of the second core.

35 [0019] A fifth configuration of the optical fiber comprises a core region extending along a predetermined axis and a cladding region provided on the outer periphery of the core region. In particular, the core region comprises a first core having a predetermined refractive index; a second core, provided on the outer periphery of the first core, having a higher refractive index than the first core; a third core, provided on the outer periphery of the second core, having a lower refractive index than the second core; and a fourth core, provided on the outer periphery of the third core, having a higher refractive index than the third core. In this fifth mode of optical fiber, the cladding region has a lower refractive index than the fourth core.

40 [0020] The optical transmission system according to the present invention is realized by the optical fiber having such a configuration as those mentioned above. Specifically, the optical transmission system according to the present invention comprises, at least, a first transmitter for outputting first light in the 1.3-μm wavelength band, a second transmitter for outputting second light in the 1.55-μm wavelength band, a multiplexer for multiplexing the first light outputted from the first transmitter and the second light outputted from the second transmitter, and an optical fiber comprising a configuration mentioned above and having one end thereof optically connected to the first multiplexer. As a result of 45 this structure, the optical fiber transmits each of the first light and second light multiplexed by the multiplexer. According to the optical transmission system having such a structure, the first light in the 1.3-μm wavelength band outputted from the first transmitter is made incident on the above-mentioned optical fiber by way of the multiplexer and propagates through the optical fiber toward a receiving system. On the other hand, the second light in the 1.55-μm wavelength band outputted from the second transmitter is made incident on the optical fiber by way of the multiplexer and propagates 50 through the optical fiber toward the receiving system. Also, as mentioned above, the optical fiber applied to the optical transmission line comprises a structure enabling efficient optical communications in each of the 1.3-μm wavelength band and 1.55-μm wavelength band, whereby the optical transmission system enables large-capacity communications when the optical fiber having such a special structure is employed therewith.

Brief Description of the Drawings**[0021]**

- 5 Fig. 1A is a graph showing a transmission loss characteristic of an optical fiber according to the present invention with respect to wavelength, whereas Fig. 1B is a graph showing a dispersion characteristic of the optical fiber according to the present invention with respect to wavelength;
- 10 Fig. 2A is a view showing a cross-sectional structure of first and thirteenth embodiments of the optical fiber according to the present invention, whereas Fig. 2B is a refractive index profile of the optical fiber according to the first embodiment shown in Fig. 2A;
- Fig. 3 is a refractive index profile of an optical fiber according to a second embodiment;
- Fig. 4 is a refractive index profile of optical fibers according to third, fifteenth, and seventeenth embodiments;
- Fig. 5 is a refractive index profile of an optical fiber according to a fourth embodiment;
- 15 Fig. 6 is a refractive index profile of optical fibers according to fifth, sixteenth, eighteenth, nineteenth, and twenty-first embodiments;
- Fig. 7 is a refractive index profile of optical fibers according to sixth, twentieth, and twenty-second embodiments;
- Fig. 8 is a refractive index profile of optical fibers according to seventh and eighth embodiments;
- Fig. 9 is a refractive index profile of optical fibers according to ninth and tenth embodiments;
- 20 Fig. 10 is a refractive index profile of optical fibers according to eleventh and twelfth embodiments;
- Fig. 11 is a table listing various characteristics of the optical fibers according to the first to thirteenth embodiments having various refractive index profiles as shown in Figs. 2B and 3 to 10;
- Fig. 12 is a table listing various characteristics of the optical fibers according to the fourteenth to twenty-second embodiments;
- 25 Fig. 13 is a graph showing a dispersion characteristic of the optical fiber according to the first embodiment with respect to wavelength;
- Fig. 14 is a graph showing a transmission loss characteristic with respect to wavelength of an optical fiber according to the first embodiment in which dehydration processing has been insufficient;
- Fig. 15 is a graph showing a transmission loss characteristic with respect to wavelength of optical fibers according to the first and thirteenth embodiments in which dehydration processing has been carried out sufficiently;
- 30 Fig. 16 is a graph showing a transmission loss characteristic with respect to wavelength of an optical fiber according to the thirteenth embodiment in which dehydration processing has been insufficient;
- Fig. 17A is a graph showing relationships between effective area A_{eff} and dispersion slope at a wavelength of 1.55 μm mainly concerning the eighteenth to twenty-second embodiments, whereas Fig. 17B is a graph showing relationships between cutoff wavelength λ_c and bending loss per turn when bent at a diameter of 32 mm at a wavelength of 1.55 μm concerning main embodiments; and
- 35 Fig. 18A is a view showing a schematic configuration of the optical transmission system according to the present invention, whereas Fig. 18B is a view showing a modified example of the optical transmission system according to the present invention.

40 Best Modes for Carrying Out the Invention

- [0022]** In the following, embodiments of the optical fiber and optical transmission system according to the present invention will be explained with reference to Figs. 1A to 2B, 3 to 16, and 17A to 18B. Among the drawings, constituents identical to each other will be referred to with numerals or letters identical to each other without repeating their overlapping explanations.
- [0023]** First, Fig. 1A is a graph showing a transmission loss characteristic of an optical fiber according to the present invention with respect to wavelength, whereas Fig. 1B is a graph showing a dispersion characteristic of the optical fiber according to the present invention with respect to wavelength.
- [0024]** The optical fiber according to the present invention has only one zero-dispersion wavelength within a wavelength range of 1.20 μm to 1.60 μm , whereas this zero-dispersion wavelength exists within a wavelength range of 1.37 μm to 1.50 μm . Since a transmission loss due to OH absorption occurs near a wavelength of 1.38 μm as shown in the graph of Fig. 1A (see, for example, KAZUHIRO NOGUCHI et al., "Loss Increase for Optical Fibers Exposed to Hydrogen Atmosphere," JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. LT-3, NO. 2, APRIL 1985), it is not always favorable to apply signal light in the vicinity of this wavelength to optical communications. Therefore, as shown in Fig. 1B, the zero-dispersion wavelength in the optical fiber according to the present invention is set within a wavelength range of 1.37 μm to 1.43 μm including the wavelength of 1.38 μm at which the transmission loss due to OH absorption occurs, but is kept from being set in the vicinity of the 1.3- μm wavelength band and 1.5- μm wavelength band sandwiching this wavelength band. When the wavelength band including the wavelength of 1.38 μm is utilized as a signal light wavelength

band, the zero-dispersion wavelength may be set within a range of longer than 1.45 μm but not longer than 1.50 μm . Thus, the 1.3- μm wavelength band and 1.55- μm wavelength band deviated from a predetermined wavelength band including the zero-dispersion wavelength are utilized as a signal wavelength band in the optical fiber according to the present invention, so that dispersion is intentionally generated in these wavelength bands, while the occurrence of four-wave mixing is effectively suppressed. When the zero-dispersion wavelength is set within the range of 1.37 μm to 1.43 μm as mentioned above, the transmission band can further be widened by use of a thulium-doped fiber amplifier whose amplification band lies in a 1.47- μm wavelength band. In the case where the above-mentioned OH absorption peak is kept low by dehydration processing or the like, so as to utilize the wavelength band including the wavelength of 1.38 μm as a signal light wavelength band, on the other hand, the zero-dispersion wavelength may be set within a wavelength range of longer than 1.45 μm but not longer than 1.50 μm in order to intentionally generate dispersion in the above-mentioned wavelength band.

[0025] Also, the optical fiber according to the present invention has a dispersion with an absolute value of 0.10 ps/nm²/km or less at the above-mentioned zero-dispersion wavelength (preferably 0.06 ps/nm²/km or less at a wavelength of 1.55 μm), thereby being able to realize homogenization of the respective dispersions in the 1.3- μm wavelength band and 1.55- μm wavelength band. Here, in this optical fiber, each of the absolute value of dispersion D_{1.3} at a wavelength of 1.3 μm and the absolute value of dispersion D_{1.55} at a wavelength of 1.55 μm is 6 ps/nm/km or more but 12 ps/nm/km or less. Even in view of the fact that a standard single-mode optical fiber having a zero-dispersion wavelength in the 1.3- μm wavelength band has a dispersion value of about 17 ps/nm/km in the 1.55- μm wavelength band, the optical fiber according to the present invention has a sufficiently small absolute value of dispersion (12 ps/nm/km or less) in each of the 1.3- μm wavelength band and 1.55- μm wavelength band, thus being more suitably utilized in optical communications. Since dispersion occurs to an appropriate extent (6 ps/nm/km or more) in these wavelength bands, on the other hand, four-wave mixing can effectively be kept from occurring.

[0026] Further, from the viewpoint of guaranteeing a single mode, the optical fiber according to the present invention preferably has a cutoff wavelength of 1.3 μm or shorter when its transmission length is not longer than several hundreds of meters. In this case, only ground-mode light can propagate in each of the 1.3- μm wavelength band and 1.55- μm wavelength band. Also, in view of the dependence of cutoff wavelength on distance, the cutoff wavelength may be 1.45 μm or shorter in optical transmission over a relatively long distance (a transmission line length of several kilometers or less). In this specification, the cutoff wavelength is that of LP11 mode measured in a state where an optical fiber having a length of 2 m is wound by only one turn at a radius of 140 mm as defined in a CCITT standard. From the viewpoint of reducing the bending loss, there are cases where the bending loss remarkably increases when the cutoff wavelength is shorter than 1.0 μm . Therefore, the cutoff wavelength is preferably 1.05 μm or more, more preferably 1.30 μm or more.

[0027] As mentioned above, the optical fiber according to the present invention is a single-mode optical fiber in which a zero-dispersion wavelength is set within a wavelength range deviated from both of the 1.3- μm wavelength band and 1.55- μm wavelength band, while the dispersion value is small in each wavelength band, whereby it is suitable as a transmission medium in an optical communication system utilizing a plurality of wavelength bands.

[0028] The optical fiber according to the present invention preferably has a dispersion slope monotonously changing within a wavelength range of 1.30 μm to 1.55 μm (monotonously increasing in the case shown in Fig. 1B). This case is preferable not only in that only one zero-dispersion wavelength can be set within a wavelength range of 1.20 μm to 1.60 μm , but also in that the dispersion in each of the 1.3- μm wavelength band and 1.55- μm wavelength band would not approach zero (because nonlinear optical phenomena are likely to occur when the dispersion approaches zero).

[0029] The optical fiber according to the present invention preferably has a bending loss of 0.5 dB/turn or less, more preferably 0.06 dB/turn or less at a wavelength of 1.55 μm when wound at a diameter of 32 mm. In this case, since the bending loss is sufficiently small, the increase in loss caused by cabling and the like can effectively be suppressed. Here, this bending loss (dB/turn) is a value obtained when the transmission loss of light having a wavelength of 1.55 μm concerning an optical fiber wound about a mandrel having a diameter of 32 mm is converted into a loss value per turn.

[0030] In the optical fiber according to the present invention, the effective area A_{eff} at a wavelength of 1.55 μm is preferably 45 μm^2 or more, more preferably greater than 49 μm^2 . This value is on a par with or greater than the effective area in a conventional dispersion-shifted optical fiber having a zero-dispersion wavelength in the 1.55- μm wavelength band, so that the optical intensity per unit cross-sectional area decreases, whereby the occurrence of nonlinear optical phenomena such as four-wave mixing is effectively suppressed.

[0031] In the optical fiber according to the present invention, the amount of increase α in transmission loss caused by OH absorption at a wavelength of 1.38 μm is preferably 0.1 dB/km or less. It is because of the fact that the wavelength band applicable to optical communications is widened thereby, so as to enable larger-capacity optical communications. In the case where a wavelength band including a wavelength of 1.38 μm is utilized as a signal light wavelength band, the zero-dispersion wavelength is preferably designed to lie within a wavelength range of longer than 1.45 μm but not longer than 1.50 μm deviated from the above-mentioned wavelength band, in order to suppress the occurrence of

nonlinear optical phenomena.

[0032] Preferably, the optical fiber according to the present invention has a refractive index profile in which the maximum and minimum values of relative refractive index difference with reference to the refractive index of pure silica (silica which is not intentionally doped with impurities) are 1% or less and -0.5% or more, respectively. Since the relative refractive index difference of a high refractive index region doped with Ge element, for example, with respect to pure silica is 1% or less, whereas the relative refractive index difference of a low refractive index region doped with F element, for example, with respect to pure silica is -0.5% or more, an optical transmission medium which is relatively easy to make and has a low transmission loss is obtained. For further facilitating the manufacture, the minimum value of relative refractive index difference with reference to the refractive index of pure silica is preferably -0.2% or more, more preferably greater than -0.15%.

[0033] First to twenty-second embodiments of the optical fiber according to the present invention will now be explained with reference to Figs. 2A, 2B, and 3 to 10.

(First Embodiment)

[0034] Fig. 2A is a view showing a cross-sectional structure of an optical fiber 100 according to the first embodiment, whereas Fig. 2B is a refractive index profile of the optical fiber 100 shown in Fig. 1A. The optical fiber 100 according to the first embodiment comprises a core region 110, with an outside diameter 2a, extending along a predetermined axis and having a refractive index n_1 , and a cladding region 120, provided on the outer periphery of the core region 110, having a refractive index n_2 ($n_2 < n_1$). Here, the refractive index of the core region 110 is higher than that of the cladding region 120. The outside diameter 2a of the core region 110 is 5.2 μm , whereas the relative refractive index difference Δ_1 of the core region 110 with reference to the cladding region 120 is 0.55%. Such an optical fiber is obtained when, while silica is used as a base, the core region 110 is doped with Ge element, for example.

[0035] The abscissa of the refractive index profile 150 shown in Fig. 2B corresponds to individual parts, along the line L in Fig. 2A, on a cross section perpendicular to the center axis of the core region 110. Hence, in the refractive index profile 150 of Fig. 2B, areas 151 and 152 indicate the refractive indices in individual parts on the line L of the core region 110 and the cladding region 120, respectively.

[0036] Here, the relative refractive index difference Δ_1 of the core region 110 with respect to the outermost cladding region 120 is defined as follows:

30

$$\Delta_1 = (n_1 - n_2)/n_2$$

35 where n_1 is the refractive index of the core region 110, and n_2 is the refractive index of the cladding region 120. Also, in this specification, the relative refractive index difference Δ is expressed in terms of percentage, and the respective refractive indices of individual regions in the above-mentioned defining expression may be arranged in any order. Consequently, a negative value of Δ indicates that the refractive index of its corresponding region is lower than that of the cladding region 120.

[0037] The optical fiber according to the first embodiment has a zero-dispersion wavelength at 1.44 μm , and only 40 this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.060 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.054 ps/nm²/km, and the cutoff wavelength is 0.96 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -18.5 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -9.6 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 0.6 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 6.2 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 8.8 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.06 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 49.1 μm^2 .

45

(Second Embodiment)

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[0038] Fig. 3 is a refractive index profile of an optical fiber according to the second embodiment. The basic configuration of the optical fiber according to the second embodiment is similar to that of the first embodiment shown in Fig. 2A, but is different therefrom in that the cladding region 120 shown in Fig. 2A is modified to have a depressed cladding structure. Referring to Fig. 2A for explanation, the optical fiber according to the second embodiment comprises a core region 110 with an outside diameter 2a having a refractive index n_1 , and a cladding region 120 provided on the outer periphery of the core region 110. The cladding region 120 is constituted by an inner cladding with an outside diameter 2b, provided in contact with the core region 110, having a refractive index n_3 ($n_3 < n_1$); and an outer cladding, provided 55 on the outer periphery of the inner cladding, having a refractive index n_2 ($n_2 < n_1, > n_3$). Here, the outside diameter 2a of

the core region 110 is 5.2 μm , whereas the outside diameter 2b of the inner cladding region is 10.9 μm . Also, with reference to the refractive index n_2 of the outer cladding region, the relative refractive index difference $\Delta_1 (= (n_1 - n_2)/n_2)$ of the core region is 0.55%, whereas the relative refractive index difference $\Delta_2 (= (n_3 - n_2)/n_2)$ of the inner cladding is -0.05%. Such an optical fiber is obtained when, for example, while silica is used as a base, the core region and the inner cladding are doped with Ge element and F element, respectively.

[0039] As for the relationship between the refractive index profile 250 shown in Fig. 3 and the cross-sectional structure shown in Fig. 2A, the abscissa of the refractive index profile 250 corresponds to individual parts, along the line L in Fig. 2A, on a cross section perpendicular to the center axis of the core region 110. Hence, in the refractive index profile 250 of Fig. 3, areas 251, 252, and 253 indicate the refractive indices in individual parts on the line L of the core region 110, the inner cladding constituting the cladding region 120, and the outer cladding constituting the cladding region 120, respectively.

[0040] The optical fiber according to the second embodiment has a zero-dispersion wavelength at 1.46 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.053 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.049 ps/nm²/km, and the cutoff wavelength is 0.93 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -18.5 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -10.1 ps/nm/km, the dispersion at a wavelength of 1.45 μm is -0.5 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 4.3 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 6.7 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.20 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 47.2 μm^2 .

(Third Embodiment)

[0041] Fig. 4 is a refractive index profile of an optical fiber according to the third embodiment. The basic configuration of the optical fiber according to the third embodiment is also similar to that of the first embodiment shown in Fig. 2A, but is different therefrom in that the core region 110 shown in Fig. 2A is constituted by a first core and a second core. Referring to Fig. 2A for explaining the configuration of the optical fiber according to the third embodiment, the core region 110 comprises a first core, with an outside diameter 2a, having a maximum refractive index n_1 at the optical axis center; and a second core with an outside diameter 2b, provided on the outer periphery of the first core, having a refractive index $n_2 (< n_1)$. The cladding region 120 provided on the outer periphery of the second core has a refractive index $n_3 (< n_2)$.

[0042] As for the relationship between the refractive index profile 350 shown in Fig. 4 and the cross-sectional structure shown in Fig. 2A, the abscissa of the refractive index profile 350 corresponds to individual parts, along the line L in Fig. 2A, on a cross section perpendicular to the center axis of the core region 110. Hence, in the refractive index profile 350 of Fig. 4, areas 351, 352, and 353 indicate the refractive indices in individual parts on the line L of the first core constituting the core region 110, the second core constituting the core region 110, and the cladding region 120, respectively. Here, the outside diameter 2a of the first core constituting the core region 110 is 6.4 μm , whereas the outside diameter 2b of the second core region is 16.0 μm . With reference to the refractive index n_3 of the cladding region 120, the relative refractive index difference $\Delta_1 (= (n_1 - n_3)/n_3)$ of the first core is 0.60%, whereas the relative refractive index difference $\Delta_2 (= (n_2 - n_3)/n_3)$ of the second core is 0.10%. Such an optical fiber is obtained when, for example, while silica is used as a base, the first core and the second core are doped with their respective appropriate amounts of Ge element.

[0043] The optical fiber according to the third embodiment has a zero-dispersion wavelength at 1.42 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.079 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.070 ps/nm²/km, and the cutoff wavelength is 1.19 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -20.8 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -10.6 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 2.1 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 9.3 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 12.8 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.006 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 63.6 μm^2 .

(Fourth Embodiment)

[0044] Fig. 5 is a refractive index profile of an optical fiber according to the fourth embodiment. As in the first embodiment shown in Fig. 2A, the optical fiber according to the fourth embodiment comprises a core region 110 and a cladding region 120. However, it differs from the above-mentioned third embodiment in that the cladding region 120 comprises a depressed structure. Referring to Fig. 2A for explaining the configuration of the optical fiber according to

the fourth embodiment, as in the third embodiment, the core region 110 comprises a first core, with an outside diameter 2a, having a maximum refractive index n_1 at the optical axis center; and a second core with an outside diameter 2b, provided on the outer periphery of the first core, having a refractive index n_2 ($< n_1$). The cladding region 120 comprises an inner cladding with an outside diameter 2c, provided in contact with the outer periphery of the second core, having a refractive index n_4 ($< n_2$); and an outer cladding, provided on the outer periphery of the inner cladding, having a refractive index n_3 ($> n_4, < n_2$).

[0045] As for the relationship between the refractive index profile 450 shown in Fig. 5 and the cross-sectional structure shown in Fig. 2A, the abscissa of the refractive index profile 450 corresponds to individual parts, along the line L in Fig. 2A, on a cross section perpendicular to the center axis of the core region 110. Hence, in the refractive index profile 450 of Fig. 5, areas 451, 452, 453, and 454 indicate the refractive indices in individual parts on the line L of the first core constituting the core region 110, the second core constituting the core region 110, the inner cladding constituting the cladding region 120, and the outer cladding constituting the cladding region 120, respectively. Here, the outside diameter 2a of the first core constituting the core region 110 is 6.3 μm , the outside diameter 2b of the second core region is 16.1 μm , and the outside diameter 2c of the inner cladding is 28.8 μm . With reference to the refractive index of pure silica, the relative refractive index difference Δ_1 ($= (n_1 - n_3)/n_3$) of the first core is 0.60%, the relative refractive index difference Δ_2 ($= (n_2 - n_3)/n_3$) of the second core is 0.10%, and the relative refractive index difference Δ_4 ($= (n_4 - n_3)/n_3$) of the inner cladding is -0.05%. Such an optical fiber is obtained when, for example, while silica is used as a base, the first core and the second core are doped with their respective appropriate amounts of Ge element, whereas the inner cladding is doped with F element.

[0046] The optical fiber according to the fourth embodiment has a zero-dispersion wavelength at 1.41 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.081 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.070 ps/nm²/km, and the cutoff wavelength is 1.15 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -20.3 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -9.9 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 3.1 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 10.2 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 13.7 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.004 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 62.0 μm^2 .

30 (Fifth Embodiment)

[0047] Fig. 6 is a refractive index profile of an optical fiber according to the fifth embodiment. The basic configuration of the optical fiber according to the fifth embodiment is also similar to the first embodiment shown in Fig. 2A, and is constituted by a core region 110 and a cladding region 120. As for the configuration of the optical fiber according to the fifth embodiment shown in Fig. 2A, the core region 110 comprises a first core, with an outside diameter 2a, extending along a predetermined axis and having a refractive index n_1 ; a second core with an outside diameter 2b, provided on the outer periphery of the first core, having a refractive index n_2 ($< n_1$); and a third core with an outside diameter 2c, provided on the outer periphery of the second core, having a refractive index n_3 ($> n_2, < n_1$). The cladding region 120 provided on the outer periphery of the third core 3 has a refractive index n_4 ($< n_1, < n_3$).

[0048] As for the relationship between the refractive index profile 550 shown in Fig. 6 and the cross-sectional structure shown in Fig. 2A, the abscissa of the refractive index profile 550 corresponds to individual parts, along the line L in Fig. 2A, on a cross section perpendicular to the center axis of the core region 110. Hence, in the refractive index profile 550 of Fig. 6, areas 551, 552, 553, and 554 indicate the refractive indices in individual parts on the line L of the first core constituting the core region 110, the second core constituting the core region 110, the third core constituting the core region 110, and the cladding region 120, respectively. Here, the outside diameter 2a of the first core is 5.3 μm , the outside diameter 2b of the second core region is 10.0 μm , and the outside diameter 2c of the third core region is 16.6 μm . With reference to the refractive index of the cladding region, the relative refractive index difference Δ_1 ($= (n_1 - n_4)/n_4$) of the first core is 0.58%, the relative refractive index difference of the second core is 0% since it is set such that $n_2 = n_4$, and the relative refractive index difference Δ_3 ($= (n_3 - n_4)/n_4$) of the third core is 0.14%. Such an optical fiber is obtained when, for example, while silica is used as a base, the first core and the third core are doped with their respective appropriate amounts of Ge element.

[0049] The optical fiber according to the fifth embodiment has a zero-dispersion wavelength at 1.48 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.064 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.064 ps/nm²/km, and the cutoff wavelength is 1.24 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -20.3 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -11.9 ps/nm/km, the dispersion at a wavelength of 1.45 μm is -1.9 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 4.8 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 8.0 ps/km.

nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.008 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 53.9 μm².

(Sixth Embodiment)

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[0050] Fig. 7 is a refractive index profile of an optical fiber according to the sixth embodiment. As in the first embodiment shown in Fig. 2A, the basic configuration of the optical fiber according to the sixth embodiment comprises a core region 110 and a cladding region 120. However, it differs from the fifth embodiment in that the cladding region 120 comprises a depressed cladding structure. Referring to Fig. 2A for explaining the configuration of the optical fiber 10 according to the sixth embodiment, the core region 110 comprises a first core, with an outside diameter 2a, extending along a predetermined axis and having a refractive index n_1 ; a second core with an outside diameter 2b, provided on the outer periphery of the first core, having a refractive index n_2 ($< n_1$); and a third core with an outside diameter 2c, provided on the outer periphery of the second core, having a refractive index n_3 ($< n_1, > n_2$). The cladding region 120 of depressed cladding structure comprises an inner cladding with an outside diameter 2d, provided on the outer periphery of the third core, having a refractive index n_5 ($< n_3$); and an outer cladding, provided on the outer periphery of the inner cladding, having a refractive index n_4 ($< n_3, > n_5$).

[0051] As for the relationship between the refractive index profile 650 shown in Fig. 7 and the cross-sectional structure shown in Fig. 2A, the abscissa of the refractive index profile 650 corresponds to individual parts, along the line L in Fig. 2A, on a cross section perpendicular to the center axis of the core region 110. Hence, in the refractive index profile 20 650 of Fig. 7, areas 651, 652, 653, 654, and 655 indicate the refractive indices in individual parts on the line L of the first core constituting the core region 110, the second core constituting the core region 110, the third core constituting the core region 110, the inner cladding constituting the cladding region 120, and the outer cladding constituting the cladding region 120, respectively. Here, the outside diameter 2a of the first core is 5.7 μm, the outside diameter 2b of the second core is 16.2 μm, the outside diameter 2c of the third core region is 23.0 μm, and the outside diameter 2d of the inner cladding 2d is 34.4 μm. With reference to the refractive index of the outer cladding region, the relative refractive index difference Δ_1 ($= (n_1 - n_4)/n_4$) of the first core is 0.50%, the relative refractive index difference of the second core is 0% since it is set such that $n_2 = n_4$, the relative refractive index difference Δ_3 ($= (n_3 - n_4)/n_4$) of the third core is 0.16%, and the relative refractive index difference Δ_5 ($= (n_5 - n_4)/n_4$) of the inner cladding is -0.10%. Such an optical fiber is obtained when, for example, while silica is used as a base, the first core and the third core are doped 25 with their respective appropriate amounts of Ge element, whereas the inner cladding is doped with F element.

[0052] The optical fiber according to the sixth embodiment has a zero-dispersion wavelength at 1.42 μm, and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm. The dispersion slope at the zero-dispersion wavelength is 0.056 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.052 ps/nm²/km, and the cutoff wavelength is 1.23 μm. Also, the dispersion slope monotonously increases at least in a wavelength 35 range of 1.30 μm to 1.55 μm; and, specifically, the dispersion at a wavelength of 1.20 μm is -16.4 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -7.9 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 1.6 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 6.6 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 9.2 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.02 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 57.1 μm².

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(Seventh and Eighth Embodiments)

[0053] Fig. 8 is a refractive index profile of optical fibers according to the seventh and eighth embodiments. Both of the seventh and eighth embodiments have the same configuration, each comprising a core region 110 and a cladding 45 region 120 as with the first embodiment shown in Fig. 2A. Referring to Fig. 2A for explaining the configuration of the optical fibers according to the seventh and eighth embodiments, the core region 110 comprises a first core, with an outside diameter 2a, extending along a predetermined axis and having a refractive index n_1 ; and a second core with an outside diameter 2b, provided on the outer periphery of the first core, having a refractive index n_2 ($> n_1$). The cladding region 120, provided on the outer periphery of the second core, has a refractive index n_3 ($< n_2$).

[0054] As for the relationship between the refractive index profile 750 shown in Fig. 8 and the cross-sectional structure shown in Fig. 2A, the abscissa of the refractive index profile 750 corresponds to individual parts, along the line L in Fig. 2A, on a cross section perpendicular to the center axis of the core region 110. Hence, in the refractive index profile 50 750 of Fig. 8, areas 751, 752, and 753 indicate the refractive indices in individual parts on the line L of the first core constituting the core region 110, the second core constituting the core region 110, and the cladding region 120, respectively.

[0055] In the optical fiber according to the seventh embodiment, the outside diameter 2a of the first core is 2.8 μm, whereas the outside diameter 2b of the second core is 5.6 μm. With reference to the refractive index of the cladding region, the relative refractive index difference Δ_1 of the first core is 0% since it is set such that $n_1 = n_3$, whereas the

relative refractive index difference $\Delta_2 (= (n_2 - n_3)/n_3)$ of the second core is 0.7%. Such an optical fiber is obtained when, for example, while silica is used as a base, the second core is doped with Ge element.

[0056] The optical fiber according to the seventh embodiment has a zero-dispersion wavelength at 1.41 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.075 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.061 ps/nm²/km, and the cutoff wavelength is 1.10 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -20.1 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -9.3 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 3.0 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 9.4 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 12.4 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.3 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 67.3 μm^2 .

[0057] In the optical fiber according to the eighth embodiment, on the other hand, the outside diameter 2a of the first core is 3.2 μm , whereas the outside diameter 2b of the second core is 6.4 μm . With reference to the refractive index of the cladding region, the relative refractive index difference $\Delta_1 (= (n_1 - n_3)/n_3)$ of the first core is -0.2%, whereas the relative refractive index difference $\Delta_2 (= (n_2 - n_3)/n_3)$ of the second core is 0.7%. Such an optical fiber is obtained when, for example, while silica is used as a base, the first core and the second core are doped with F element and Ge element, respectively.

[0058] The optical fiber according to the eighth embodiment has a zero-dispersion wavelength at 1.42 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.084 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.068 ps/nm²/km, and the cutoff wavelength is 1.17 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -22.9 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -11.1 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 2.4 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 9.9 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 13.2 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.2 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 79.1 μm^2 .

(Ninth and Tenth Embodiments)

[0059] Fig. 9 is a refractive index profile of optical fibers according to the ninth and tenth embodiments. Both of the ninth and tenth embodiments have the same configuration, each comprising a core region 110 and a cladding region 120 as with the first embodiment shown in Fig. 2A. However, the ninth and tenth embodiments differ from the seventh and eighth embodiments in that the cladding region 120 comprises a depressed cladding structure. Referring to Fig. 2A for explaining the configuration of the optical fibers according to the ninth and tenth embodiments, the core region 110 comprises a first core, with an outside diameter 2a, extending along a predetermined axis and having a refractive index n_1 ; and a second core with an outside diameter 2b, provided on the outer periphery of the first core, having a refractive index $n_2 (> n_1)$. The cladding region with the depressed cladding structure comprises an inner cladding with an outside diameter 2c, provided on the outer periphery of the second core, having a refractive index $n_4 (< n_1)$; and an outside cladding, provided on the outer periphery of the inner cladding, having a refractive index $n_3 (> n_4)$.

[0060] As for the relationship between the refractive index profile 850 shown in Fig. 9 and the cross-sectional structure shown in Fig. 2A, the abscissa of the refractive index profile 850 corresponds to individual parts, along the line L in Fig. 2A, on a cross section perpendicular to the center axis of the core region 110. Hence, in the refractive index profile 850 of Fig. 9, areas 851, 852, 853, and 854 indicate the refractive indices in individual parts on the line L of the first core constituting the core region 110, the second core constituting the core region 110, the inner cladding constituting the cladding region 120, and the outer cladding constituting the cladding region 120, respectively.

[0061] In the optical fiber according to the ninth embodiment, the outside diameter 2a of the first core is 3.8 μm , the outside diameter 2b of the second core is 7.1 μm , and the outside diameter 2c of the inner cladding is 10.6 μm . With reference to the refractive index of the outer cladding, the relative refractive index difference Δ_1 of the first core is 0% since it is set such that $n_1 = n_3$, the relative refractive index difference $\Delta_2 (= (n_2 - n_3)/n_3)$ of the second core is 0.7%, and the relative refractive index difference $\Delta_4 (= (n_4 - n_3)/n_3)$ of the inner cladding is -0.2%. Such an optical fiber is obtained when, for example, while silica is used as a base, the second core and the inner cladding are doped with Ge element and F element, respectively.

[0062] The optical fiber according to the ninth embodiment has a zero-dispersion wavelength at 1.42 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.077 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.061 ps/nm²/km, and the cutoff wavelength is 1.22 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -21.6 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -10.2 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 2.2 ps/nm/km,

the dispersion at a wavelength of 1.55 μm is 9.1 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 12.1 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.2 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 73.5 μm².

[0063] In the optical fiber according to the tenth embodiment, on the other hand, the outside diameter 2a of the first core is 2.6 μm, the outside diameter 2b of the second core is 6.4 μm, and the outside diameter 2c of the inner cladding is 9.6 μm. With reference to the refractive index of the outer cladding, the relative refractive index difference Δ_1 ($= (n_1 - n_3)/n_3$) of the first core is -0.2%, the relative refractive index difference Δ_2 ($= (n_2 - n_3)/n_3$) of the second core is 0.7%, and the relative refractive index difference Δ_4 ($= (n_4 - n_3)/n_3$) of the inner cladding is -0.2%. Such an optical fiber is obtained when, for example, while silica is used as a base, the second core is doped with Ge element, whereas the first core and the inner cladding are each doped with F element.

[0064] The optical fiber according to the tenth embodiment has a zero-dispersion wavelength at 1.44 μm, and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm. The dispersion slope at the zero-dispersion wavelength is 0.070 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.058 ps/nm²/km, and the cutoff wavelength is 1.18 μm. Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm; and, specifically, the dispersion at a wavelength of 1.20 μm is -21.5 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -10.8 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 0.7 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 7.3 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 10.1 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.03 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 59.6 μm².

(Tenth and Eleventh Embodiments)

[0065] Fig. 10 is a refractive index profile of optical fibers according to the eleventh and twelfth embodiments. Both of the eleventh and twelfth embodiments have the same configuration, each comprising a core region 110 and a cladding region 120 as with the first embodiment shown in Fig. 2A. Referring to Fig. 2A for explaining the configuration of the optical fibers according to the eleventh and twelfth embodiments, the core region 110 comprises a first core, with an outside diameter 2a, extending along a predetermined axis and having a refractive index n_1 ; a second core with an outside diameter 2b, provided on the outer periphery of the first core, having a refractive index n_2 ($> n_1$); a third core with an outside diameter 2c, provided on the outer periphery of the second core, having a refractive index n_3 ($< n_2$); and, a fourth core with an outside diameter 2d, provided on the outer periphery of the third core, having a refractive index n_4 ($< n_2, > n_3$). The cladding region 120 provided on the outer periphery of the fourth core has a refractive index n_5 ($< n_4$).

[0066] As for the relationship between the refractive index profile 950 shown in Fig. 10 and the cross-sectional structure shown in Fig. 2A, the abscissa of the refractive index profile 950 corresponds to individual parts, along the line L in Fig. 2A, on a cross section perpendicular to the center axis of the core region 110. Hence, in the refractive index profile 950 of Fig. 10, areas 951, 952, 953, 954, and 955 indicate the refractive indices in individual parts on the line L of the first core constituting the core region 110, the second core constituting the core region 110, the third core constituting the core region 110, the fourth core constituting the core region 110, and the cladding region 120, respectively.

[0067] In the optical fiber according to the eleventh embodiment, the outside diameter 2a of the first core is 2.7 μm, the outside diameter 2b of the second core is 5.4 μm, the outside diameter 2b of the third core is 8.1 μm, and the outside diameter 2d of the fourth core is 10.8 μm. With reference to the refractive index of the cladding region, the relative refractive index difference Δ_1 of the first core is 0% since it is set such that $n_1 = n_3$, the relative refractive index difference Δ_2 ($= (n_2 - n_5)/n_5$) of the second core is 0.8%, the relative refractive index difference Δ_3 of the third core is 0% since it is set such that $n_3 = n_5$, and the relative refractive index difference Δ_4 ($= (n_4 - n_5)/n_5$) of the fourth core is 0.1%. Such an optical fiber is obtained when, for example, while silica is used as a base, the second core and the fourth core are each doped with Ge.

[0068] The optical fiber according to the eleventh embodiment has a zero-dispersion wavelength at 1.42 μm, and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm. The dispersion slope at the zero-dispersion wavelength is 0.080 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.065 ps/nm²/km, and the cutoff wavelength is 1.16 μm. Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm; and, specifically, the dispersion at a wavelength of 1.20 μm is -21.8 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -10.5 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 2.3 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 9.5 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 12.7 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.005 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 62.6 μm².

[0069] In the optical fiber according to the twelfth embodiment, on the other hand, the outside diameter 2a of the first core is 3.2 μm, the outside diameter 2b of the second core is 7.0 μm, the outside diameter 2c of the third core is 9.0

μm , and the outside diameter $2d$ of the fourth core $2d$ is $12.8 \mu\text{m}$. With reference to the refractive index of the cladding region, the relative refractive index difference $\Delta_1 (= (n_1 - n_5)/n_5)$ of the first core is -0.2% , the relative refractive index difference $\Delta_2 (= (n_2 - n_5)/n_5)$ of the second core is 0.6% , the relative refractive index difference $\Delta_3 (= (n_3 - n_5)/n_5)$ of the third core is -0.2% , and the relative refractive index difference $\Delta_4 (= (n_4 - n_5)/n_5)$ of the fourth core is 0.1% . Such an optical fiber is obtained when, for example, while silica is used as a base, the second core and the fourth core are each doped with Ge element, whereas the first core and the third core are each doped with F element.

[0070] The optical fiber according to the twelfth embodiment has a zero-dispersion wavelength at $1.41 \mu\text{m}$, and only this one zero-dispersion wavelength exists within a wavelength range of $1.20 \mu\text{m}$ to $1.60 \mu\text{m}$. The dispersion slope at the zero-dispersion wavelength is $0.088 \text{ ps/nm}^2/\text{km}$, the dispersion slope at a wavelength of $1.55 \mu\text{m}$ is $0.071 \text{ ps/nm}^2/\text{km}$, and the cutoff wavelength is $1.22 \mu\text{m}$. Also, the dispersion slope monotonously increases at least in a wavelength range of $1.30 \mu\text{m}$ to $1.55 \mu\text{m}$; and, specifically, the dispersion at a wavelength of $1.20 \mu\text{m}$ is -22.5 ps/nm/km , the dispersion at a wavelength of $1.30 \mu\text{m}$ is -10.6 ps/nm/km , the dispersion at a wavelength of $1.45 \mu\text{m}$ is 3.4 ps/nm/km , the dispersion at a wavelength of $1.55 \mu\text{m}$ is 11.0 ps/nm/km , and the dispersion at a wavelength of $1.60 \mu\text{m}$ is 14.5 ps/nm/km . Further, the bending loss at a wavelength of $1.55 \mu\text{m}$ when wound at a diameter of 32 mm is 0.4 dB per turn , whereas the effective area A_{eff} at the wavelength of $1.55 \mu\text{m}$ is $92.7 \mu\text{m}^2$.

(Thirteenth Embodiment)

[0071] The thirteenth embodiment of the optical fiber according to the present invention has a cross-sectional structure and a refractive index profile such as those basically shown in Figs. 2A and 2B. However, the optical fiber according to the thirteenth embodiment differs from the first embodiment in that, while silica is used as a base, the cladding region 120 excluding the core region 110 is doped with fluorine (refractive index lowering agent), so as to generate a relative refractive index difference between the core region 110 and the cladding region 120.

[0072] In the optical fiber according to the thirteenth embodiment, the core region 110 made of pure silica (with a refractive index n_0) has an outside diameter $2a$ of $5.6 \mu\text{m}$. With reference to the refractive index $n_2 (< n_0)$ of the cladding region 120, the relative refractive index difference $\Delta_1 (= (n_0 - n_2)/n_2)$ of the core region 110 is 0.53% . Also, though the core region 110 is constituted by pure silica (silica which is not intentionally doped with impurities) in the thirteenth embodiment, it may be made of silica doped with chlorine.

[0073] The optical fiber according to the thirteenth embodiment has a zero-dispersion wavelength at $1.41 \mu\text{m}$, and only this one zero-dispersion wavelength exists within a wavelength range of $1.20 \mu\text{m}$ to $1.60 \mu\text{m}$. The dispersion slope at the zero-dispersion wavelength is $0.057 \text{ ps/nm}^2/\text{km}$, the dispersion slope at a wavelength of $1.55 \mu\text{m}$ is $0.048 \text{ ps/nm}^2/\text{km}$, and the cutoff wavelength is $1.04 \mu\text{m}$. Also, the dispersion slope monotonously increases at least in a wavelength range of $1.30 \mu\text{m}$ to $1.55 \mu\text{m}$; and, specifically, the dispersion at a wavelength of $1.20 \mu\text{m}$ is -15.7 ps/nm/km , the dispersion at a wavelength of $1.30 \mu\text{m}$ is -7.2 ps/nm/km , the dispersion at a wavelength of $1.45 \mu\text{m}$ is 2.2 ps/nm/km , the dispersion at a wavelength of $1.55 \mu\text{m}$ is 7.1 ps/nm/km , and the dispersion at a wavelength of $1.60 \mu\text{m}$ is 9.4 ps/nm/km . Further, the bending loss at a wavelength of $1.55 \mu\text{m}$ when wound at a diameter of 32 mm is 0.04 dB per turn , whereas the effective area A_{eff} at the wavelength of $1.55 \mu\text{m}$ is $52.2 \mu\text{m}^2$.

[0074] In addition, the optical fiber according to the thirteenth embodiment yields a transmission loss of 0.17 dB/km at a wavelength of $1.55 \mu\text{m}$, thus being an optical fiber of a lower transmission loss as compared with the embodiments whose core region is doped with Ge (yielding a transmission loss of about 0.20 dB/km at the wavelength of $1.55 \mu\text{m}$).

(Fourteenth Embodiment)

[0075] The fourteenth embodiment of the optical fiber according to the present invention has a refractive index profile similar to that of the third embodiment shown in Fig. 4, while having an effective area of about $50 \mu\text{m}^2$ at a wavelength of $1.55 \mu\text{m}$. However, the profile form of the fourteenth embodiment differs from that of the third embodiment in that the refractive index (n_1) of the first core is radially uniform.

[0076] As in the above-mentioned third embodiment, the optical fiber according to the fourteenth embodiment comprises a first core having a refractive index n_1 ; a second core, provided on the outer periphery of the first core, having a refractive index $n_2 (< n_1)$; and a cladding region, provided on the outer periphery of the second core, having a refractive index $n_3 (< n_2)$.

[0077] In the optical fiber according to the fourteenth embodiment, the outside diameter $2a$ of the first core is $5.5 \mu\text{m}$, whereas the outside diameter $2b$ of the second core is $23.7 \mu\text{m}$. With reference to the refractive index n_3 of the cladding region, the relative refractive index difference $\Delta_1 (= (n_1 - n_3)/n_3)$ of the first core is 0.59% , whereas the relative refractive index difference $\Delta_2 (= (n_2 - n_3)/n_3)$ of the second core is 0.06% .

[0078] The optical fiber according to the fourteenth embodiment has a zero-dispersion wavelength at $1.41 \mu\text{m}$, and only this one zero-dispersion wavelength exists within a wavelength range of $1.20 \mu\text{m}$ to $1.60 \mu\text{m}$. The dispersion slope at the zero-dispersion wavelength is $0.065 \text{ ps/nm}^2/\text{km}$, the dispersion slope at a wavelength of $1.55 \mu\text{m}$ is $0.055 \text{ ps/nm}^2/\text{km}$, and the cutoff wavelength is $1.22 \mu\text{m}$. Also, the dispersion slope monotonously increases at least in a wavelength range of $1.30 \mu\text{m}$ to $1.55 \mu\text{m}$; and, specifically, the dispersion at a wavelength of $1.20 \mu\text{m}$ is -22.5 ps/nm/km , the dispersion at a wavelength of $1.30 \mu\text{m}$ is -10.6 ps/nm/km , the dispersion at a wavelength of $1.45 \mu\text{m}$ is 3.4 ps/nm/km , the dispersion at a wavelength of $1.55 \mu\text{m}$ is 11.0 ps/nm/km , and the dispersion at a wavelength of $1.60 \mu\text{m}$ is 14.5 ps/nm/km .

nm²/km, and the cutoff wavelength is 1.25 μm. Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm; and, specifically, the dispersion at a wavelength of 1.20 μm is -16.8 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -7.7 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 2.5 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 8.5 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 11.2 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.00002 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 50.1 μm².

(Fifteenth Embodiment)

- [0079] The fifteenth embodiment of the optical fiber according to the present invention also has a refractive index profile similar to that of the third embodiment shown in Fig. 4, while having a zero-dispersion wavelength in the vicinity of 1450 nm. However, the profile form of the fifteenth embodiment differs from that of the third embodiment in that the refractive index (n_1) of the first core is radially uniform.
- [0080] As in the above-mentioned third embodiment, the optical fiber according to the fifteenth embodiment comprises a first core having a refractive index n_1 ; a second core, provided on the outer periphery of the first core, having a refractive index n_2 (< n_1); and a cladding region, provided on the outer periphery of the second core, having a refractive index n_3 (< n_2).
- [0081] In the optical fiber according to the fifteenth embodiment, the outside diameter 2a of the first core is 4.8 μm, whereas the outside diameter 2b of the second core is 15.1 μm. With reference to the refractive index n_3 of the cladding region, the relative refractive index difference Δ_1 (= $(n_1 - n_3)/n_3$) of the first core is 0.65%, whereas the relative refractive index difference Δ_2 (= $(n_2 - n_3)/n_3$) of the second core is 0.06%.
- [0082] The optical fiber according to the fifteenth embodiment has a zero-dispersion wavelength at 1.46 (1.457) μm, and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm. The dispersion slope at the zero-dispersion wavelength is 0.060 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.060 ps/nm²/km, and the cutoff wavelength is 1.07 μm. Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm; and, specifically, the dispersion at a wavelength of 1.20 μm is -20.2 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -11.1 ps/nm/km, the dispersion at a wavelength of 1.45 μm is -0.6 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 5.7 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 8.7 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.00006 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 45.3 μm².

(Sixteenth Embodiment)

- [0083] The sixteenth embodiment of the optical fiber according to the present invention has a refractive index profile similar to that of the fifth embodiment shown in Fig. 6, but differs therefrom in that the refractive index (n_2) of the second core is set higher than the refractive index (n_4) of the cladding region and in that the form of the refractive index profile of the first core is an α-type distribution (dome form such as one shown in Fig. 5).
- [0084] As in the above-mentioned fifth embodiment, the optical fiber according to the sixteenth embodiment comprises a first core having a maximum refractive index n_1 ; a second core, provided on the outer periphery of the first core, having a refractive index n_2 (< n_1); a third core, provided on the outer periphery of the second core, having a refractive index n_3 (> n_2 , < n_1); and a cladding region, provided on the outer periphery of the third core, having a refractive index n_4 (< n_3).
- [0085] In the optical fiber according to the sixteenth embodiment, the outside diameter 2a of the first core is 6.7 μm, the outside diameter 2b of the second core is 13.4 μm, and the outside diameter 2c of the third core is 22.4 μm. With reference to the refractive index n_4 of the cladding region, the relative refractive index difference Δ_1 (= $(n_1 - n_4)/n_4$) of the first core is 0.60%, the relative refractive index difference Δ_2 (= $(n_2 - n_4)/n_4$) of the second core is 0.05%, and the relative refractive index difference Δ_3 (= $(n_3 - n_4)/n_4$) of the third core is 0.11%.
- [0086] The optical fiber according to the sixteenth embodiment has a zero-dispersion wavelength at 1.47 μm, and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm. The dispersion slope at the zero-dispersion wavelength is 0.065 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.065 ps/nm²/km, and the cutoff wavelength is 1.37 μm. Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm; and, specifically, the dispersion at a wavelength of 1.20 μm is -21.1 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -12.1 ps/nm/km, the dispersion at a wavelength of 1.45 μm is -1.3 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 5.1 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 8.4 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.02 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 62.6 μm².

(Seventeenth Embodiment)

[0087] The seventeenth embodiment of the optical fiber according to the present invention has a refractive index profile similar to that of the third embodiment shown in Fig. 4, while having a cutoff wavelength longer than its signal light wavelength.

[0088] As in the above-mentioned third embodiment, the optical fiber according to the seventeenth embodiment comprises a first core having a refractive index n_1 ; a second core, provided on the outer periphery of the first core, having a refractive index n_2 ($< n_1$); and a cladding region, provided on the outer periphery of the second core, having a refractive index n_3 ($< n_2$).

[0089] In the optical fiber according to the seventeenth embodiment, the outside diameter $2a$ of the first core is 7.5 μm , whereas the outside diameter $2b$ of the second core is 29.0 μm . With reference to the refractive index n_3 of the cladding region, the relative refractive index difference Δ_1 ($= (n_1 - n_3)/n_3$) of the first core is 0.61%, whereas the relative refractive index difference Δ_2 ($= (n_2 - n_3)/n_3$) of the second core is 0.10%.

[0090] The optical fiber according to the seventeenth embodiment has a zero-dispersion wavelength at 1.40 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.071 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.059 ps/nm²/km, and the cutoff wavelength is 1.78 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -17.4 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -7.7 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 3.5 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 9.7 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 12.6 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.00002 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 60.3 μm^2 .

[0091] As for the optical fiber having a triple structure in which the core region is constituted by the first to third cores as shown in Figs. 6 and 7, a plurality of embodiments having such a low dispersion slope that the dispersion at a wavelength of 1.55 μm is 0.06 ps/nm²/km or less will now be explained.

(Eighteenth Embodiment)

[0092] The eighteenth embodiment of the optical fiber according to the present invention has a refractive index profile similar to that of the fifth embodiment shown in Fig. 6, while having a low dispersion slope.

[0093] As in the above-mentioned fifth embodiment, the optical fiber according to the eighteenth embodiment comprises a first core having a refractive index n_1 ; a second core, provided on the outer periphery of the first core, having a refractive index n_2 ($< n_1$); a third core, provided on the outer periphery of the second core, having a refractive index n_3 ($> n_2, < n_1$); and a cladding region, provided on the outer periphery of the third core, having a refractive index n_4 ($= n_2$).

[0094] In the optical fiber according to the eighteenth embodiment, the outside diameter $2a$ of the first core is 5.5 μm , the outside diameter $2b$ of the second core is 22.8 μm , and the outside diameter $2c$ of the third core is 34.6 μm . With reference to the refractive index n_4 of the cladding region, the relative refractive index difference Δ_1 ($= (n_1 - n_4)/n_4$) of the first core is 0.48%, the relative refractive index difference of the second core is 0% since it is set such that $n_2 = n_4$, and the relative refractive index difference Δ_3 ($= (n_3 - n_4)/n_4$) of the third core is 0.12%.

[0095] The optical fiber according to the eighteenth embodiment has a zero-dispersion wavelength at 1.41 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.058 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.040 ps/nm²/km, and the cutoff wavelength is 1.75 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -16.5 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -7.5 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 2.1 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 6.8 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 8.6 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.2 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 57.1 μm^2 .

(Nineteenth Embodiment)

[0096] The nineteenth embodiment of the optical fiber according to the present invention is also an optical fiber having a refractive index profile similar to that of the fifth embodiment shown in Fig. 6, while having a low dispersion slope. The refractive index profile of the nineteenth embodiment differs from that of the fifth embodiment or that of the above-mentioned eighteenth embodiment in that the refractive index (n_2) of the second core is set higher than the refractive index (n_4) of the cladding region.

[0097] As in the above-mentioned fifth embodiment, the optical fiber according to the nineteenth embodiment comprises a first core having a refractive index n_1 ; a second core, provided on the outer periphery of the first core, having

a refractive index $n_2 (< n_1)$; a third core, provided on the outer periphery of the second core, having a refractive index $n_3 (> n_2, < n_1)$; and a cladding region, provided on the outer periphery of the third core, having a refractive index $n_4 (< n_3)$.

[0098] In the optical fiber according to the nineteenth embodiment, the outside diameter $2a$ of the first core is $6.2 \mu\text{m}$, the outside diameter $2b$ of the second core is $19.9 \mu\text{m}$, and the outside diameter $2c$ of the third core is $28.4 \mu\text{m}$.

5 With reference to the refractive index n_4 of the cladding region, the relative refractive index difference $\Delta_1 (= (n_1 - n_4)/n_4)$ of the first core is 0.44%, the relative refractive index difference $\Delta_2 (= (n_2 - n_4)/n_4)$ of the second core is 0.01%, and the relative refractive index difference $\Delta_3 (= (n_3 - n_4)/n_4)$ of the third core is 0.13%.

[0099] The optical fiber according to the nineteenth embodiment has a zero-dispersion wavelength at $1.38 \mu\text{m}$, and only this one zero-dispersion wavelength exists within a wavelength range of $1.20 \mu\text{m}$ to $1.60 \mu\text{m}$. The dispersion slope at the zero-dispersion wavelength is $0.065 \text{ ps/nm}^2/\text{km}$, the dispersion slope at a wavelength of $1.55 \mu\text{m}$ is $0.047 \text{ ps/nm}^2/\text{km}$, and the cutoff wavelength is $1.52 \mu\text{m}$. Also, the dispersion slope monotonously increases at least in a wavelength range of $1.30 \mu\text{m}$ to $1.55 \mu\text{m}$; and, specifically, the dispersion at a wavelength of $1.20 \mu\text{m}$ is $-14.5 \text{ ps/nm}/\text{km}$, the dispersion at a wavelength of $1.30 \mu\text{m}$ is $-5.4 \text{ ps/nm}/\text{km}$, the dispersion at a wavelength of $1.45 \mu\text{m}$ is $4.4 \text{ ps/nm}/\text{km}$, the dispersion at a wavelength of $1.55 \mu\text{m}$ is $9.4 \text{ ps/nm}/\text{km}$, and the dispersion at a wavelength of $1.60 \mu\text{m}$ is $11.7 \text{ ps/nm}/\text{km}$. Further, the bending loss at a wavelength of $1.55 \mu\text{m}$ when wound at a diameter of 32 mm is 0.07 dB per turn, whereas the effective area A_{eff} at the wavelength of $1.55 \mu\text{m}$ is $64.5 \mu\text{m}^2$.

(Twentieth Embodiment)

20 [0100] As with the sixth embodiment shown in Fig. 7, the twentieth embodiment of the optical fiber according to the present invention is an optical fiber having a refractive index profile of a depressed cladding structure, while having a low dispersion slope. In the refractive index profile of the twentieth embodiment, as in the above-mentioned nineteenth embodiment, the refractive index (n_2) of the second core is set higher than the refractive index (n_4) of the cladding region.

25 [0101] In the optical fiber according to the twentieth embodiment, as in the above-mentioned sixth embodiment, the core region comprises a first core having a refractive index n_1 ; a second core, provided on the outer periphery of the first core, having a refractive index $n_2 (< n_1)$; and a third core, provided on the outer periphery of the second core, having a refractive index $n_3 (> n_2, < n_1)$. Also, the cladding region comprises an inner cladding, provided on the outer periphery of the third core, having a refractive index $n_5 (< n_3)$; and an outer cladding, provided on the outer periphery 30 of the inner cladding, having a refractive index $n_4 (< n_3, > n_5)$; whereas the inner and outer claddings constitute the depressed cladding structure.

[0102] In the optical fiber according to the twentieth embodiment, the outside diameter $2a$ of the first core is $5.6 \mu\text{m}$, the outside diameter $2b$ of the second core is $19.7 \mu\text{m}$, the outside diameter $2c$ of the third core is $28.1 \mu\text{m}$, and the outside diameter $2d$ of the inner cladding is $42.0 \mu\text{m}$. With reference to the refractive index n_4 of the outer cladding, the relative refractive index difference $\Delta_1 (= (n_1 - n_4)/n_4)$ of the first core is 0.55%, the relative refractive index difference $\Delta_2 (= (n_2 - n_4)/n_4)$ of the second core is 0.01%, the relative refractive index difference $\Delta_3 (= (n_3 - n_4)/n_4)$ of the third core is 0.16%, and the relative refractive index difference $\Delta_5 (= (n_5 - n_4)/n_4)$ of the inner cladding is -0.05%.

35 [0103] The optical fiber according to the twentieth embodiment has a zero-dispersion wavelength at $1.40 \mu\text{m}$, and only this one zero-dispersion wavelength exists within a wavelength range of $1.20 \mu\text{m}$ to $1.60 \mu\text{m}$. The dispersion slope at the zero-dispersion wavelength is $0.059 \text{ ps/nm}^2/\text{km}$, the dispersion slope at a wavelength of $1.55 \mu\text{m}$ is $0.043 \text{ ps/nm}^2/\text{km}$, and the cutoff wavelength is $1.59 \mu\text{m}$. Also, the dispersion slope monotonously increases at least in a wavelength range of $1.30 \mu\text{m}$ to $1.55 \mu\text{m}$; and, specifically, the dispersion at a wavelength of $1.20 \mu\text{m}$ is $-15.8 \text{ ps/nm}/\text{km}$, the dispersion at a wavelength of $1.30 \mu\text{m}$ is $-6.9 \text{ ps/nm}/\text{km}$, the dispersion at a wavelength of $1.45 \mu\text{m}$ is $2.7 \text{ ps/nm}/\text{km}$, the dispersion at a wavelength of $1.55 \mu\text{m}$ is $7.4 \text{ ps/nm}/\text{km}$, and the dispersion at a wavelength of $1.60 \mu\text{m}$ is $9.5 \text{ ps/nm}/\text{km}$. Further, the bending loss at a wavelength of $1.55 \mu\text{m}$ when wound at a diameter of 32 mm is 0.001 dB per turn, whereas the effective area A_{eff} at the wavelength of $1.55 \mu\text{m}$ is $50.4 \mu\text{m}^2$.

(Twenty-first Embodiment)

50 [0104] The twenty-first embodiment of the optical fiber according to the present invention is an optical fiber having a refractive index profile similar to that of the above-mentioned fifth embodiment shown in Fig. 6, while having a low dispersion slope.

[0105] As in the above-mentioned fifth embodiment, the optical fiber according to the twenty-first embodiment comprises a first core having a refractive index n_1 ; a second core, provided on the outer periphery of the first core, having a refractive index $n_2 (< n_1)$; a third core, provided on the outer periphery of the second core, having a refractive index $n_3 (> n_2, < n_1)$; and a cladding region, provided on the outer periphery of the third core, having a refractive index $n_4 (= n_2)$.

55 [0106] In the optical fiber according to the twenty-first embodiment, the outside diameter $2a$ of the first core is $6.1 \mu\text{m}$, the outside diameter $2b$ of the second core is $17.8 \mu\text{m}$, and the outside diameter $2c$ of the third core is $25.4 \mu\text{m}$.

With reference to the refractive index n_4 of the cladding region, the relative refractive index difference $\Delta_1 (= (n_1 - n_4)/n_4)$ of the first core is 0.45%, the relative refractive index difference of the second core is 0% since it is set such that $n_2 = n_4$, and the relative refractive index difference $\Delta_3 (= (n_3 - n_4)/n_4)$ of the third core is 0.14%.

[0107] The optical fiber according to the twenty-first embodiment has a zero-dispersion wavelength at 1.40 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.057 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.046 ps/nm²/km, and the cutoff wavelength is 1.44 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -15.2 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -6.5 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 2.7 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 7.5 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 9.8 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.1 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 64.4 μm^2 .

(Twenty-second Embodiment)

[0108] As in the sixth embodiment shown in Fig. 7, the twenty-second embodiment of the optical fiber according to the present invention has a refractive index profile of a depressed cladding structure, while having a low dispersion slope. In the refractive index profile of the twenty-second embodiment, contrary to the above-mentioned twentieth embodiment, the refractive index (n_2) of the second core is set lower than the refractive index (n_4) of the cladding region.

[0109] In the optical fiber according to the twenty-second embodiment, as in the above-mentioned sixth embodiment, the core region comprises a first core having a refractive index n_1 ; a second core, provided on the outer periphery of the first core, having a refractive index $n_2 (< n_1)$; and a third core, provided on the outer periphery of the second core, having a refractive index $n_3 (> n_2, < n_4)$. Also, the cladding region comprises an inner cladding, provided on the outer periphery of the third core, having a refractive index $n_5 (< n_3)$; and an outer cladding, provided on the outer periphery of the inner cladding, having a refractive index $n_4 (< n_3, > n_5)$; whereas the inner and outer claddings constitute the depressed cladding structure.

[0110] In the optical fiber according to the twenty-second embodiment, the outside diameter 2a of the first core is 6.0 μm , the outside diameter 2b of the second core is 19.7 μm , the outside diameter 2c of the third core is 30.0 μm , and the outside diameter 2d of the inner cladding is 44.8 μm . With reference to the refractive index n_4 of the outer cladding, the relative refractive index difference $\Delta_1 (= (n_1 - n_4)/n_4)$ of the first core is 0.46%, the relative refractive index difference $\Delta_2 (= (n_2 - n_4)/n_4)$ of the second core is -0.05%, the relative refractive index difference $\Delta_3 (= (n_3 - n_4)/n_4)$ of the third core is 0.16%, and the relative refractive index difference $\Delta_5 (= (n_5 - n_4)/n_4)$ of the inner cladding is -0.05%.

[0111] The optical fiber according to the twenty-second embodiment has a zero-dispersion wavelength at 1.39 μm , and only this one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm . The dispersion slope at the zero-dispersion wavelength is 0.052 ps/nm²/km, the dispersion slope at a wavelength of 1.55 μm is 0.023 ps/nm²/km, and the cutoff wavelength is 1.66 μm . Also, the dispersion slope monotonously increases at least in a wavelength range of 1.30 μm to 1.55 μm ; and, specifically, the dispersion at a wavelength of 1.20 μm is -14.4 ps/nm/km, the dispersion at a wavelength of 1.30 μm is -5.7 ps/nm/km, the dispersion at a wavelength of 1.45 μm is 2.8 ps/nm/km, the dispersion at a wavelength of 1.55 μm is 5.9 ps/nm/km, and the dispersion at a wavelength of 1.60 μm is 7.0 ps/nm/km. Further, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.3 dB per turn, whereas the effective area A_{eff} at the wavelength of 1.55 μm is 55.6 μm^2 .

[0112] Fig. 11 is a table listing various characteristics of respective optical fibers according to the above-mentioned first to thirteenth embodiments. Also, Fig. 12 is a table listing various characteristics of respective optical fibers according to the above-mentioned fourteenth to twenty-second embodiments. As shown in these tables, each of the optical fibers according to the first to twenty-second embodiments has only one zero-dispersion wavelength within a wavelength range of 1.20 μm to 1.60 μm , whereas this zero-dispersion wavelength lies within a wavelength range of 1.37 μm to 1.50 μm . In particular, the zero-dispersion wavelength lies within a wavelength range of 1.37 μm to 1.43 μm in the third, fourth, sixth to ninth, eleventh to fourteenth, and seventeenth to twenty-second embodiments, whereas it lies within a wavelength range of longer than 1.45 μm but not longer than 1.55 μm in the second, fifth, fifteenth, and sixteenth embodiments. In each of the embodiments, the absolute value of dispersion slope at the zero-dispersion wavelength is 0.10 ps/nm²/km or less, whereas the cutoff wavelength is 1.3 μm or shorter. Therefore, each of these optical fibers is of a single mode having no zero-dispersion wavelength at the 1.3- μm wavelength band nor 1.5- μm wavelength band, while the dispersion at each of these wavelength bands is kept low, thereby being suitable for optical communications utilizing a plurality of wavelength bands. At a wavelength of 1.55 μm , the first, second, sixth, thirteenth to fifteenth, and eighteenth to twenty-second embodiments have a dispersion slope of 0.06 ps/nm²/km, with the eighteenth to twenty-second embodiments having a further lower dispersion slope in particular.

[0113] Also, in each of the optical fibers according to the first to twenty-second embodiments, the dispersion slope monotonously changes in a wavelength range of 1.30 μm to 1.55 μm , whereas the absolute value of dispersion at

wavelengths of 1.3 μm and 1.55 μm is 12 ps/nm/km or less. Therefore, the absolute value of dispersion in the 1.3-μm wavelength band and 1.55-μm wavelength band in each of these optical fibers is sufficiently smaller than the dispersion value (about 17 ps/nm/km) in the 1.55-μm wavelength band of a conventional standard single-mode optical fiber having a zero-dispersion wavelength in the 1.3-μm wavelength band. If the dispersion value up to that (about 17 ps/nm/km)

5 in the 1.55-μm wavelength band of the above-mentioned standard single-mode optical fiber is permissible in an optical transmission system as a whole, then each of the respective optical fibers according to the first to twenty-second embodiments is suitably utilized in optical communications having a signal light wavelength band within a range of 1.2 μm to 1.7 μm.

10 [0114] Further, each of the optical fibers according to the first to twenty-second embodiments has a bending loss of 0.5 dB or less per turn at a wavelength of 1.55 μm when wound at a diameter of 32 mm, with this bending loss being 0.06 dB or less in the first to sixth, eleventh, thirteenth to seventeenth, nineteenth, and twentieth embodiments in particular, and thus is preferable in that it can effectively suppress the increase in loss caused by cabling and the like. Also, each of the optical fibers according to the first to twenty-second embodiments has an effective area A_{eff} of 45 μm² or more at a wavelength of 1.55 μm, with the effective area A_{eff} in the first, third to fourteenth, and sixteenth to 15 twenty-second embodiments exceeding 49 μm² in particular, which is on a par with or greater than the effective area of conventional dispersion-shifted optical fibers. Hence, the light propagating through the optical fiber has a lower intensity per unit cross-sectional area, whereby nonlinear optical phenomena such as four-wave mixing can effectively be suppressed.

20 [0115] In the refractive index profiles 150 to 950 shown in Figs. 2B, and 3 to 10, the maximum and minimum values of relative refractive index difference with reference to the refractive index of the reference region (the cladding region 120, or the outer cladding if the cladding region 120 has a depressed cladding structure) of pure silica (silica which is not intentionally doped with impurities) is 1% or less and -0.5% or more, respectively, except for the above-mentioned thirteenth embodiment. Though the thirteenth embodiment comprises a structure in which the cladding region 120 is doped with fluorine so as to relatively enhance the difference in refractive index between the core region made of pure 25 silica and the cladding region, the maximum value of relative refractive index difference of the core region 110 with respect to the cladding region 120 is 1% or less even in this embodiment. While a high refractive index region is realized by doping with Ge element, for example; since its relative refractive index difference is 1% or less, the making of this optical fiber (refractive index control by doping with impurities) is relatively easy, and its transmission loss becomes smaller. While a low refractive index region, on the other hand, is realized by doping with F element, for example; since 30 its relative refractive index difference is -0.5% or more, the making of this optical fiber is easy in this regard as well.

35 [0116] Fig. 13 is a graph showing a dispersion characteristic of the optical fiber according to the first embodiment with respect to wavelength. As shown in this graph, the dispersion slope monotonously increases in a wavelength range of 1.30 μm to 1.55 μm. Also, Figs. 14 and 15 are graphs showing transmission loss characteristics with respect to wavelength of the optical fiber according to the first embodiment in cases where dehydration processing is insufficient and sufficient, respectively. As shown in these graphs, an increase in transmission loss caused by OH absorption is seen at a wavelength of 1.38 μm. In an optical fiber having such a transmission loss characteristic as that shown in Fig. 14, the dehydration processing is not sufficiently effected, so that the OH group content is large, whereby the amount of increase in transmission loss caused by OH absorption is about 0.5 dB/km. An optical fiber having such a transmission loss characteristic as that shown in Fig. 15, on the other hand, the dehydration processing is sufficiently 40 effected so as to reduce the OH group content, whereby the increase in transmission loss caused by OH absorption is suppressed to about 0.01 dB/km. When the above-mentioned wavelength band is utilized as a signal wavelength band, the zero-dispersion wavelength can be set within a range of longer than 1.45 μm but not longer than 1.55 μm. The same holds true for the respective dispersion characteristics and transmission characteristics with respect to wavelength of the optical fibers according to the second to twelfth and fourteenth to twenty-second embodiments.

45 [0117] Also, Fig. 16 is a graph showing a transmission loss characteristic with respect to wavelength of the optical fiber according to the thirteenth embodiment in the case where the dehydration processing is insufficient. In the thirteenth embodiment, the increase in transmission loss caused by OH absorption (at a wavelength of 1.38 μm) is 0.3 dB/km when the dehydration processing is not sufficiently effected. If the dehydration processing is sufficiently effected, however, then the increase in transmission loss at a wavelength of 1.3 μm (at a wavelength of 1.38 μm) can be suppressed to 0.01 dB/km or less, as shown in Fig. 14, also in the case of the thirteenth embodiment.

50 [0118] Without being restricted to the above-mentioned individual embodiments, the optical fiber according to the present invention can be modified in various manners; and, for example, other designs are possible within the scope of the present invention.

[0119] Fig. 17A is a graph showing relationships between effective area A_{eff} and dispersion slope at a wavelength of 1.55 μm mainly concerning the eighteenth to twenty-second embodiments. In this graph, P1, P5, P7, P9, P10, and P18 to P22 are points indicating the relationships between effective area A_{eff} and dispersion slope in the first, fifth, seventh, ninth, tenth, and eighteenth to twenty-second embodiments, respectively.

[0120] As can also be seen from this graph, the dispersion slope at a wavelength of 1.55 μm can particularly be

lowered in the case of optical fibers (eighteenth to twenty-second embodiments) having such a refractive index profile as that shown in Fig. 6. Also, the effective area A_{eff} at a wavelength of 1.55 μm in the optical fibers according to the eighteenth to twenty-second embodiments is greater than 49 μm^2 .

[0121] Further, Fig. 17B is a graph showing relationships between cutoff wavelength λ_c and bending loss per turn when bent at a diameter of 32 mm at a wavelength of 1.55 μm concerning main embodiments. In this graph, P1, P3, P4, P6, P7, P10, and P14 to P16 show the relationships between cutoff wavelength λ_c and bending loss in the first, third, fourth, sixth, seventh, tenth, and fourteenth to sixteenth embodiments, respectively. Also, the hatched portion in this graph is an area in which points indicating relationships between cutoff wavelength λ_c and bending loss are intensively plotted with regard to conventional optical fibers having a refractive index profile similar to that shown in Fig. 6. Therefore, for avoiding this area (hatched portion), i.e., for yielding a bending loss of 1.0 dB/turn or less, preferably 0.06 dB/turn or less at 32 mm at a wavelength of 1.55 μm , it is preferred that the cutoff wavelength λ_c be 1.05 μm or more, more preferably 1.3 μm or more.

[0122] Embodiments of the optical transmission system according to the present invention will now be explained. Fig. 18A is a view showing a schematic configuration of an embodiment of the optical transmission system according to the present invention. The optical transmission system shown in this drawing comprises transmitters 11, 12; optical transmission lines 21, 22; a multiplexer 30; an optical fiber 40; a demultiplexer 50; optical transmission lines 61, 62; and receivers 71, 72.

[0123] The transmitter 11 outputs signal light (first signal light) in the 1.3- μm wavelength band; whereas the optical transmission line 21 is a transmission medium for guiding the signal light in the 1.3- μm wavelength band outputted from the transmitter 11 to the multiplexer 30 and, for example, is a standard single-mode optical fiber having a zero-dispersion wavelength in the 1.3- μm wavelength band. The transmitter 12 outputs signal light (second signal light) in the 1.55- μm wavelength band; whereas the optical transmission line 22 is a transmission medium for guiding the signal light in the 1.55- μm wavelength band outputted from the transmitter 12 to the multiplexer 30 and, for example, is a dispersion-shifted optical fiber having a zero-dispersion wavelength in the 1.55- μm wavelength band.

[0124] The multiplexer 30 multiplexes the signal light in the 1.3- μm wavelength band and signal light in the 1.55- μm wavelength band propagated through the optical transmission lines 21, 22, and outputs thus multiplexed light to the optical fiber 40. The optical fiber 40 transmits the signal light in the 1.3- μm wavelength band and signal light in the 1.55- μm wavelength band multiplexed by the multiplexer 30 toward the demultiplexer 50. The demultiplexer 50 demultiplexes the signal light in the 1.3- μm wavelength band and signal light in the 1.55- μm wavelength band propagated through the optical fiber 40.

[0125] The above-mentioned optical fiber 40 is an optical fiber according to the present invention having a configuration mentioned above, in which only one zero-dispersion wavelength exists within a wavelength range of 1.20 μm to 1.60 μm , whereas this zero-dispersion wavelength lies within a wavelength range of 1.37 μm to 1.50 μm (preferably within a wavelength range of 1.37 μm to 1.43 μm or within a wavelength range of longer than 1.45 μm but not longer than 1.50 μm). Also, in the optical fiber 40, the absolute value of dispersion slope at the zero-dispersion wavelength is 0.10 ps/nm²/km or less (preferably 0.06 ps/nm²/km or less at a wavelength of 1.55 μm). In a more preferred embodiment, the optical fiber 40 has a dispersion slope monotonously changing in a wavelength range of 1.30 μm to 1.55 μm , whereas each of the absolute values of dispersion at wavelengths of 1.3 μm and 1.55 μm is 12 ps/nm/km or less, the bending loss at a wavelength of 1.55 μm when wound at a diameter of 32 mm is 0.5 dB or less (preferably 0.06 dB or less) per turn, the effective area A_{eff} at the wavelength of 1.55 μm is 45 μm^2 or more (greater than 49 μm^2), or the increase in transmission loss caused by OH absorption at a wavelength of 1.38 μm is 0.1 dB/km or less.

[0126] The optical transmission line 61 is a transmission medium for guiding the signal light in the 1.3- μm wavelength band demultiplexed by the demultiplexer 50 to the receiver 71 and, for example, is a standard single-mode optical fiber having a zero-dispersion wavelength in the 1.3- μm wavelength band. The receiver 71 receives the signal light in the 1.3- μm wavelength band propagated through the optical transmission line 61. On the other hand, the optical transmission line 62 is a transmission medium for guiding the signal light in the 1.55- μm wavelength band demultiplexed by the demultiplexer 50 to the receiver 72 and, for example, is a dispersion-shifted optical fiber having a zero-dispersion wavelength in the 1.55- μm wavelength band. The receiver 72 receives the signal light in the 1.55- μm wavelength band propagated through the optical transmission line 62.

[0127] In the optical transmission system according to this embodiment, the signal light in the 1.3- μm wavelength band having arrived at the multiplexer 30 by way of the optical transmission line 21 after being outputted from the transmitter 11, and the signal light in the 1.55- μm wavelength band having arrived at the multiplexer 30 by way of the optical transmission line 22 after being outputted from the transmitter 12 are multiplexed by the multiplexer 30, and thus multiplexed light propagates through the optical fiber 40 and reaches the demultiplexer 50. The multiplexed light having arrived at the demultiplexer 50 is demultiplexed thereby into the signal light in the 1.3- μm wavelength band and the signal light in the 1.55- μm wavelength band. The demultiplexed signal light in the 1.3- μm wavelength band reaches the receiver 71 by way of the optical transmission line 61, whereas the signal light in the 1.55- μm wavelength band reaches the receiver 72 by way of the optical transmission line 62.

[0128] Thus, the optical fiber 40 used in the optical transmission system of this embodiment comprises a structure which realizes favorable optical communications in both of the 1.3- μm wavelength band and 1.55- μm wavelength band, whereby the optical transmission system employing the optical fiber 40 enables large-capacity communications.

[0129] Without being restricted to the above-mentioned embodiment, the optical fiber according to the present invention can be modified in various manners. For example, the optical fiber, which is a transmission medium, disposed between the multiplexer 30 and demultiplexer 50 may be constituted by a plurality of optical fibers 40a to 40c as shown in Fig. 18B.

Industrial Applicability

[0130] According to the present invention, as explained in the foregoing, the optical fiber has only one zero-dispersion wavelength within a wavelength range of 1.37 μm to 1.50 μm including a wavelength of 1.38 μm at which an increase in transmission loss caused by OH absorption is seen, preferably within a wavelength range of 1.37 μm to 1.43 μm , or within a wavelength range of longer than 1.45 μm but not longer than 1.50 μm , whereas no zero-dispersion wavelength exists in the vicinity of the 1.3- μm wavelength band and 1.55- μm wavelength band sandwiching these wavelength ranges. Therefore, when these wavelength bands are utilized as a signal light wavelength band, dispersion is intentionally generated, so as to effectively suppress nonlinear optical phenomena such as four-wavemixing. Also, since the absolute value of dispersion slope at thus set zero-dispersion wavelength is 0.10 ps/nm²/km or less (preferably 0.06 ps/nm²/km or less at a wavelength of 1.55 μm), the respective dispersions in the 1.3- μm wavelength band and 1.55- μm wavelength band are homogenized. When such an optical fiber is employed in the transmission line of the optical transmission system, favorable optical communications are possible in both of the 1.3- μm wavelength band and 1.55- μm wavelength band.

Claims

1. An optical fiber having only one zero-dispersion wavelength within a wavelength range of 1.20 μm to 1.60 μm ,
said zero-dispersion wavelength existing within a wavelength range of 1.37 μm to 1.50 μm ,
said optical fiber having a positive dispersion slope at said zero-dispersion wavelength.
2. An optical fiber according to claim 1, wherein said zero-dispersion wavelength exists within a wavelength range of 1.37 μm or more but 1.43 μm or less.
3. An optical fiber according to claim 1, wherein said zero-dispersion wavelength exists within a wavelength range of longer than 1.45 μm but not longer than 1.50 μm .
4. An optical fiber according to claim 1, wherein said dispersion slope has an absolute value of 0.10 ps/nm²/km or less.
5. An optical fiber according to claim 1, wherein said optical fiber has a dispersion slope of 0.06 ps/nm²/km or less at a wavelength of 1.55 μm .
6. An optical fiber according to claim 1, wherein said dispersion slope monotonously changes in a wavelength range of 1.30 μm to 1.55 μm .
7. An optical fiber according to claim 1, wherein each of an absolute value of dispersion at a wavelength of 1.30 μm and an absolute value of dispersion at a wavelength of 1.55 μm is 12 ps/nm/km or less.
8. An optical fiber according to claim 7, wherein each of the absolute value of dispersion at a wavelength of 1.30 μm and the absolute value of dispersion at a wavelength of 1.55 μm is 6 ps/nm/km or more.
9. An optical fiber according to claim 1, wherein said optical fiber has a bending loss which becomes 0.5 dB/turn or less at a wavelength of 1.55 μm when wound at a diameter of 32 mm.
10. An optical fiber according to claim 9, wherein said optical fiber has a bending loss which becomes 0.06 dB/turn or less at a wavelength of 1.55 μm when wound at a diameter of 32 mm.
11. An optical fiber according to claim 1, wherein said optical fiber has an effective area of 45 μm^2 or more at a

wavelength of 1.55 µm.

12. An optical fiber according to claim 11, wherein said optical fiber has an effective area of 49 µm² or more at a wavelength of 1.55 µm.
- 5 13. An optical fiber according to claim 1, wherein an increase in transmission loss caused by OH absorption at a wavelength of 1.38 µm is 0.1 dB/km or less.
- 10 14. An optical fiber according to claim 1, wherein said optical fiber has a refractive index profile in which maximum and minimum values of relative refractive index difference with reference to a refractive index of pure silica are 1% or less and -0.5% or more, respectively.
- 15 15. An optical fiber according to claim 14, wherein said optical fiber has a refractive index profile in which the minimum value of relative refractive index difference with reference to the refractive index of pure silica is -0.2% or more.
16. An optical fiber according to claim 15, wherein said optical fiber has a refractive index profile in which the minimum value of relative refractive index difference with reference to the refractive index of pure silica is greater than -0.15%.
- 20 17. An optical fiber according to claim 1, wherein said optical fiber has a cutoff wavelength of 1.05 µm or more.
18. An optical fiber according to claim 17, wherein said optical fiber has a cutoff wavelength of 1.30 µm or more.
- 25 19. An optical fiber according to claim 1, wherein said optical fiber comprises:
 - a core region extending along a predetermined axis and having a predetermined refractive index; and
 - a cladding region provided on the outer periphery of said core region.
- 20 20. An optical fiber according to claim 19, wherein said cladding region comprises an inner cladding, in contact with the outer periphery of said core region, having a lower refractive index than said core region; and, an outer cladding, provided on the outer periphery of said inner cladding, having a refractive index higher than that of said inner cladding and lower than that of said core region.
21. An optical fiber according to claim 1, wherein said optical fiber comprises:
 - 35 a core region which is a region extending along a predetermined axis, and comprising a first core having a predetermined refractive index, and a second core, provided on the outer periphery of said first core, having a lower refractive index than said first core; and
 - a cladding region provided on the outer periphery of said core region.
- 40 22. An optical fiber according to claim 21, wherein said cladding region comprises an inner cladding, in contact with the outer periphery of said second core, having a lower refractive index than said second core; and, an outer cladding, provided on the outer periphery of said inner cladding, having a refractive index higher than that of said inner cladding and lower than that of said second core.
- 45 23. An optical fiber according to claim 1, wherein said optical fiber comprises:
 - 50 a core region which is a region extending along a predetermined axis, and comprising a first core having a predetermined refractive index, a second core, provided on the outer periphery of said first core, having a lower refractive index than said first core, and a third core, provided on the outer periphery of said second core, having a higher refractive index than said second core; and
 - a cladding region provided on the outer periphery of said core region.
24. An optical fiber according to claim 23, wherein said second core has a refractive index equal to or higher than that of said cladding region.
- 55 25. An optical fiber according to claim 23, wherein said cladding region comprises an inner cladding, in contact with the outer periphery of said third core, having a lower refractive index than said third core; and, an outer cladding, provided on the outer periphery of said inner cladding, having a refractive index higher than that of said inner

cladding and lower than that of said third core.

26. An optical fiber according to claim 25, wherein said second core has a refractive index equal to or higher than that of said outer cladding.

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27. An optical fiber according to claim 1, wherein said optical fiber comprises:

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a core region which is a region extending along a predetermined axis, and comprising a first core having a predetermined refractive index, and a second core, provided on the outer periphery of said first core, having a higher refractive index than said first core; and
a cladding region provided on the outer periphery of said core region.

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28. An optical fiber according to claim 27, wherein said cladding region comprises an inner cladding, in contact with the outer periphery of said second core, having a lower refractive index than said second core; and, an outer cladding, provided on the outer periphery of said inner cladding, having a refractive index higher than that of said inner cladding and lower than that of said second core.

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29. An optical fiber according to claim 1, wherein said optical fiber comprises:

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a core region which is a region extending along a predetermined axis, and comprising a first core having a predetermined refractive index, a second core, provided on the outer periphery of said first core, having a higher refractive index than said first core, a third core, provided on the outer periphery of said second core, having a lower refractive index than said second core, and a fourth core, provided on the outer periphery of said third core, having a higher refractive index than said third core; and
a cladding, provided on the outer periphery of said core region, having a lower refractive index than said fourth core.

30. An optical transmission system comprising:

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a first transmitter for outputting first light in a 1.3- μm wavelength band;
a second transmitter for outputting second light in a 1.55- μm wavelength band;
a multiplexer for multiplexing said first light outputted from said first transmitter and said second light outputted from said second transmitter; and
the optical fiber according to claim 1, having one end optically connected to said multiplexer, for transmitting each of said first light and second light multiplexed by said second multiplexer.

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31. An optical fiber having only one zero-dispersion wavelength within a wavelength range of 1.20 μm to 1.60 μm ,

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said zero-dispersion wavelength existing within a wavelength range of 1.37 μm to 1.50 μm ,
said optical fiber having a positive dispersion slope at said zero-dispersion wavelength and an effective area greater than 49 μm^2 at a wavelength of 1.55 μm .

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32. An optical fiber having only one zero-dispersion wavelength within a wavelength range of 1.20 μm to 1.60 μm ,
said zero-dispersion wavelength existing within a wavelength range of longer than 1.45 μm but not longer than 1.50 μm ,
said optical fiber having a positive dispersion slope at said zero-dispersion wavelength.

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33. An optical fiber having only one zero-dispersion wavelength within a wavelength range of 1.20 μm to 1.60 μm ,
said zero-dispersion wavelength existing within a wavelength range of 1.37 μm to 1.50 μm ,
said optical fiber having a positive dispersion slope at said zero-dispersion wavelength and a bending loss which becomes 0.06 dB/turn or less at a wavelength of 1.55 μm when wound at a diameter of 32 mm.

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34. An optical fiber having only one zero-dispersion wavelength within a wavelength range of 1.20 μm to 1.60 μm ,
said zero-dispersion wavelength existing within a wavelength range of 1.37 μm to 1.50 μm ,
said optical fiber having a positive dispersion slope at said zero-dispersion wavelength and a cutoff wavelength

of 1.05 µm or more.

35. An optical fiber according to claim 34, wherein said cutoff wavelength is 1.30 µm or more.

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Fig. 1A

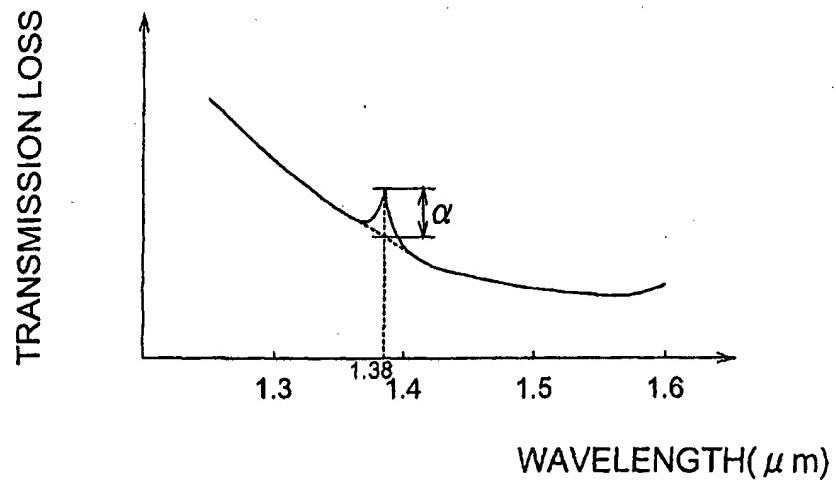


Fig. 1B

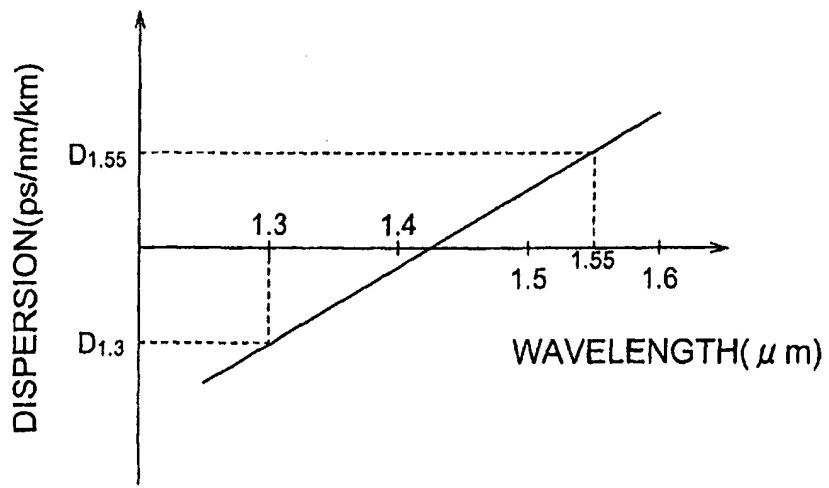


Fig.2A

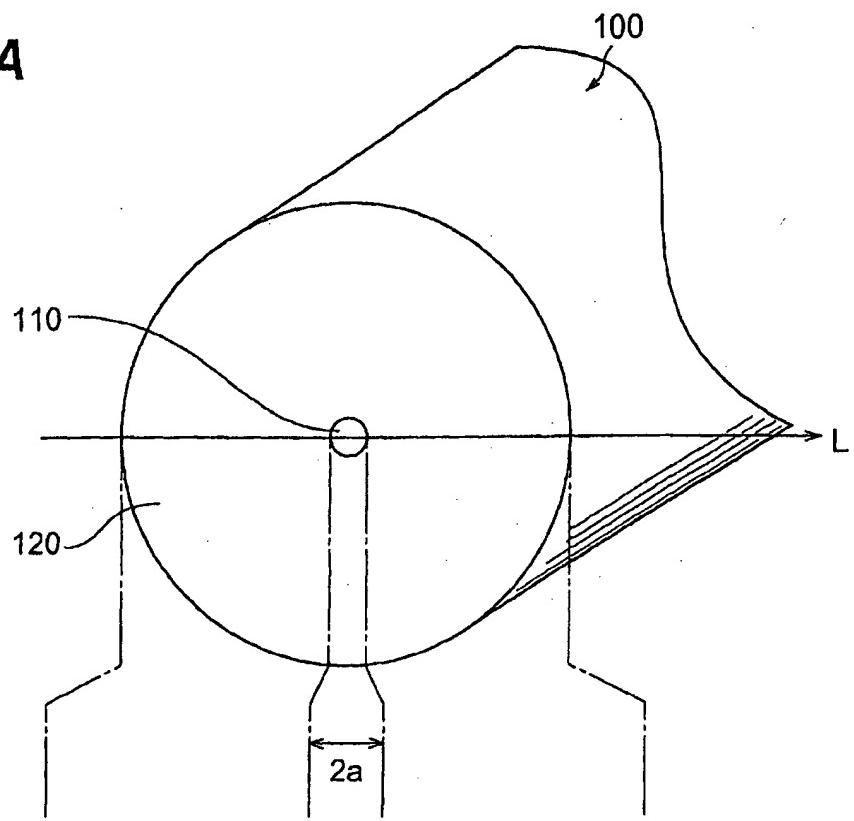


Fig.2B

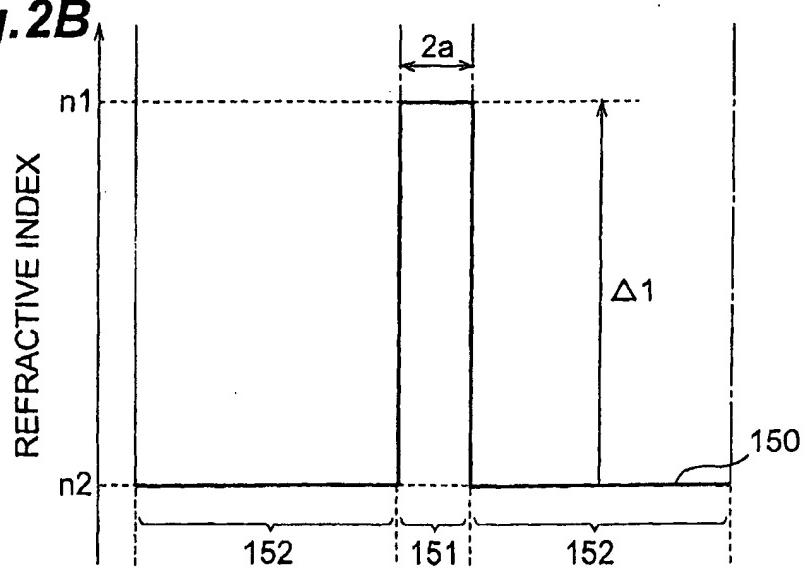


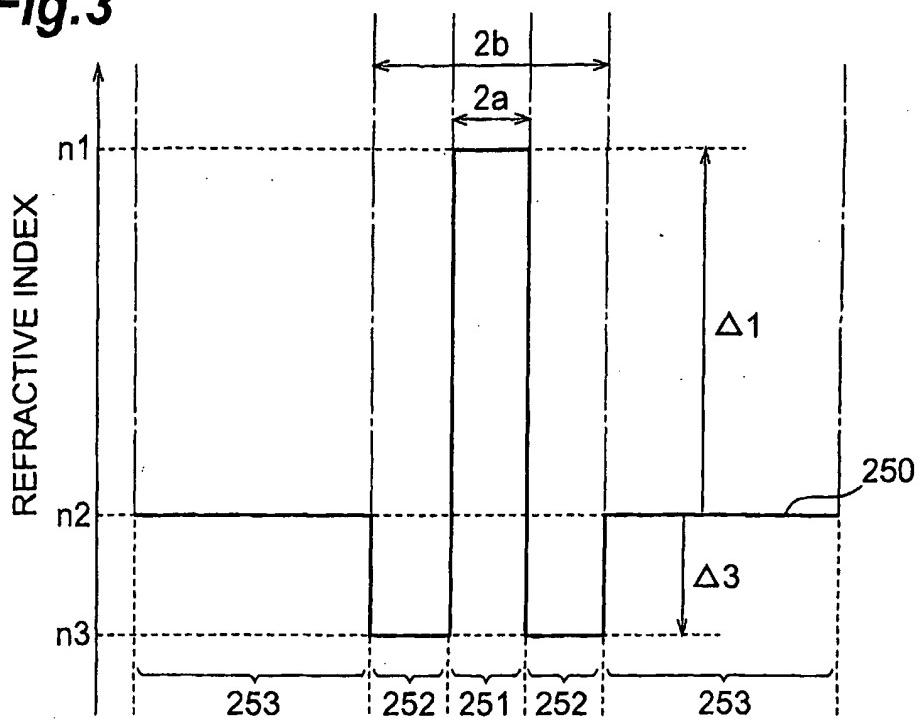
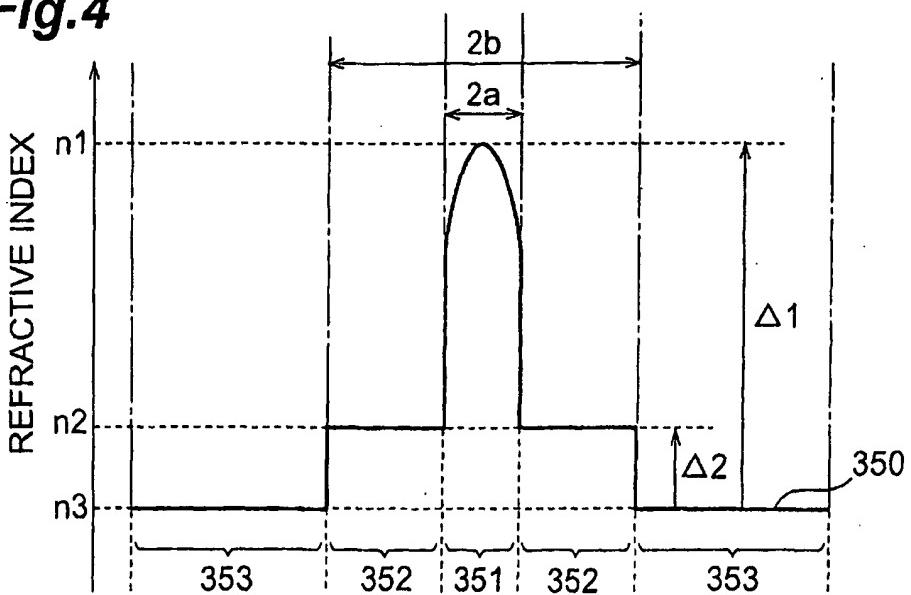
Fig.3**Fig.4**

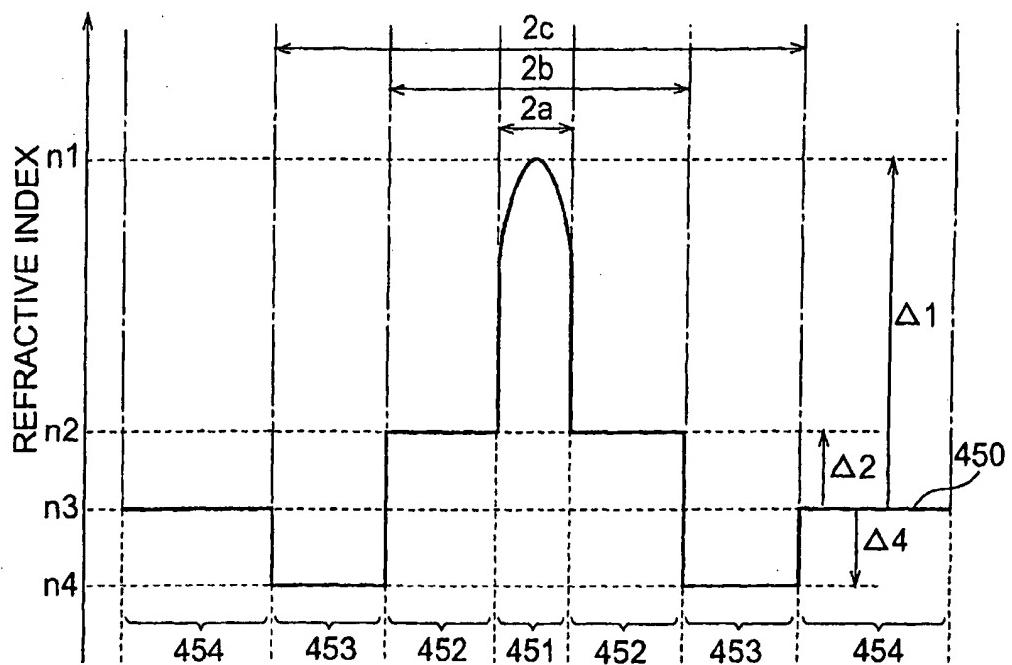
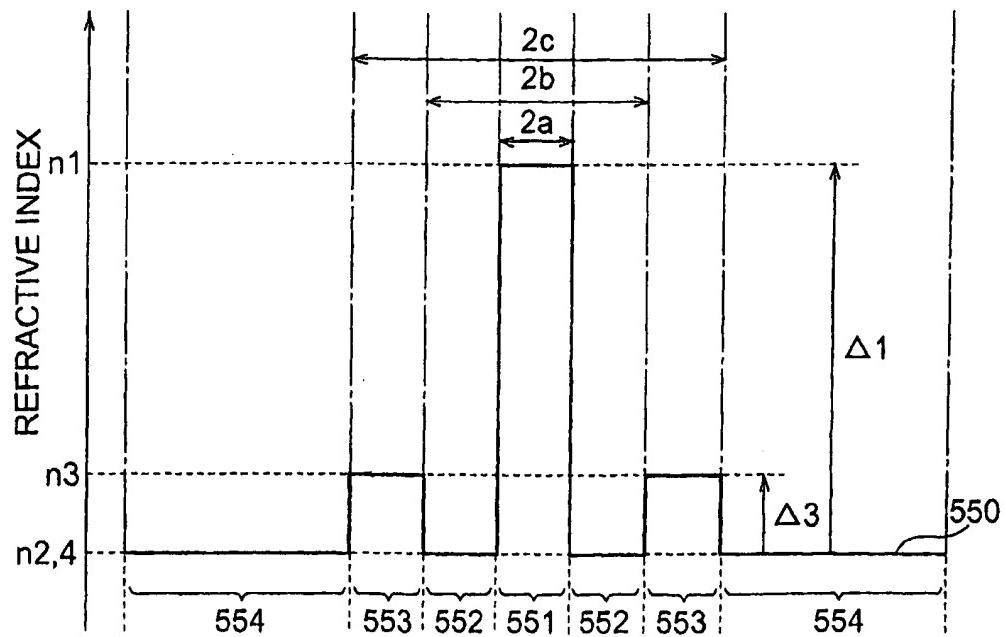
Fig.5***Fig.6***

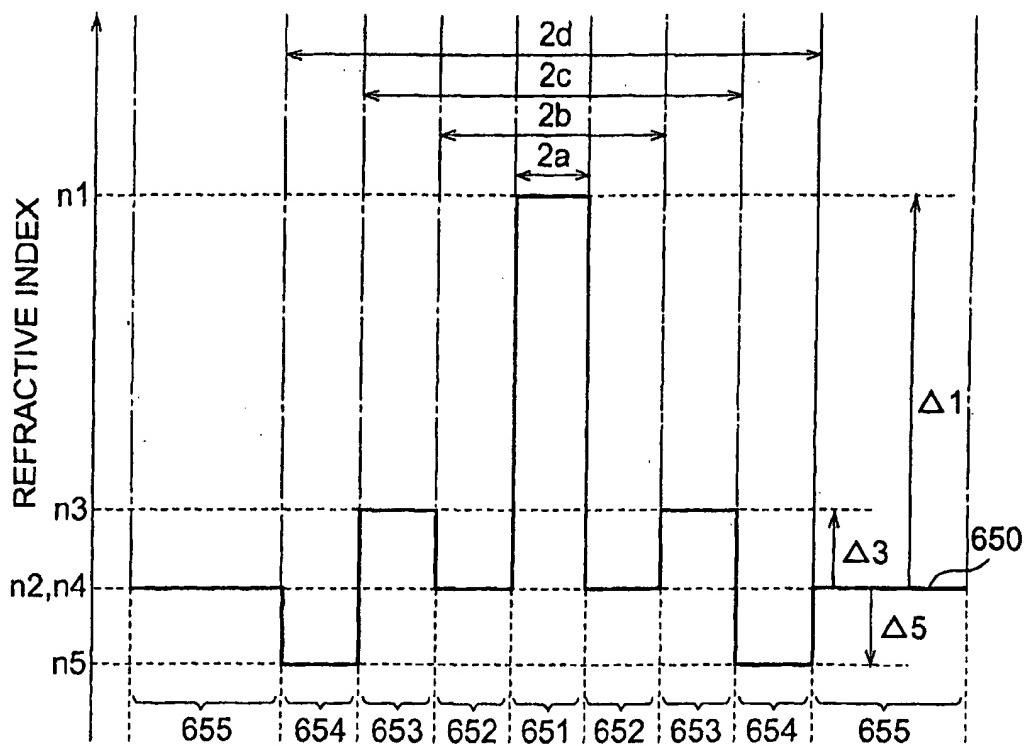
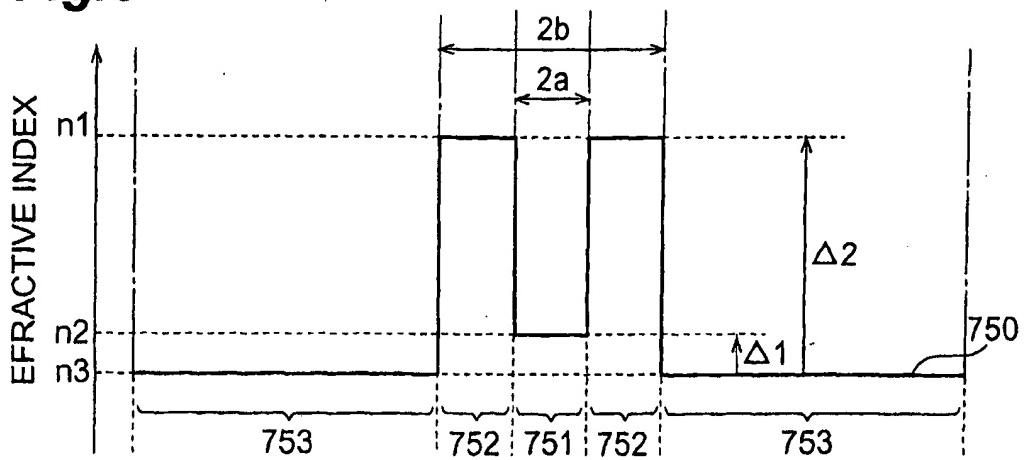
Fig.7*Fig.8*

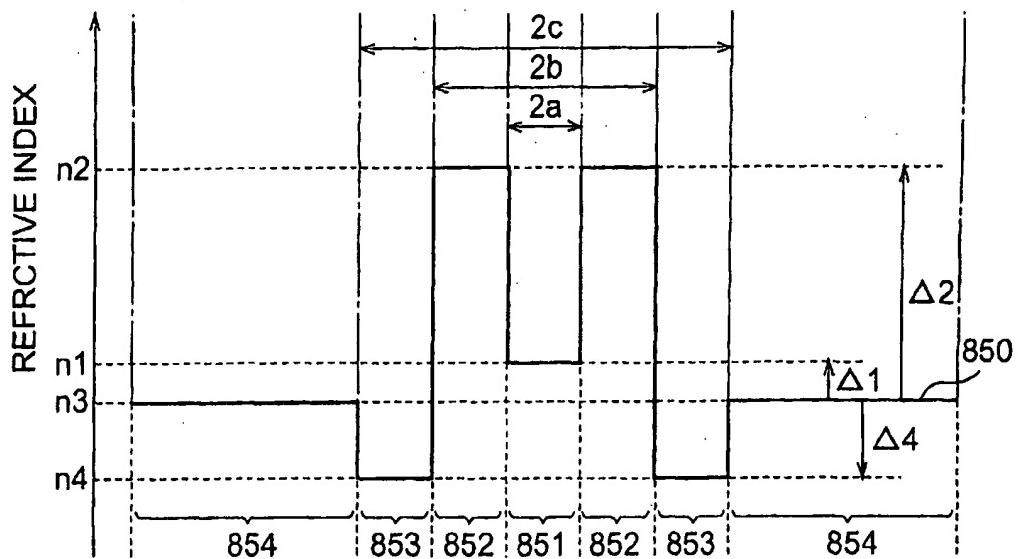
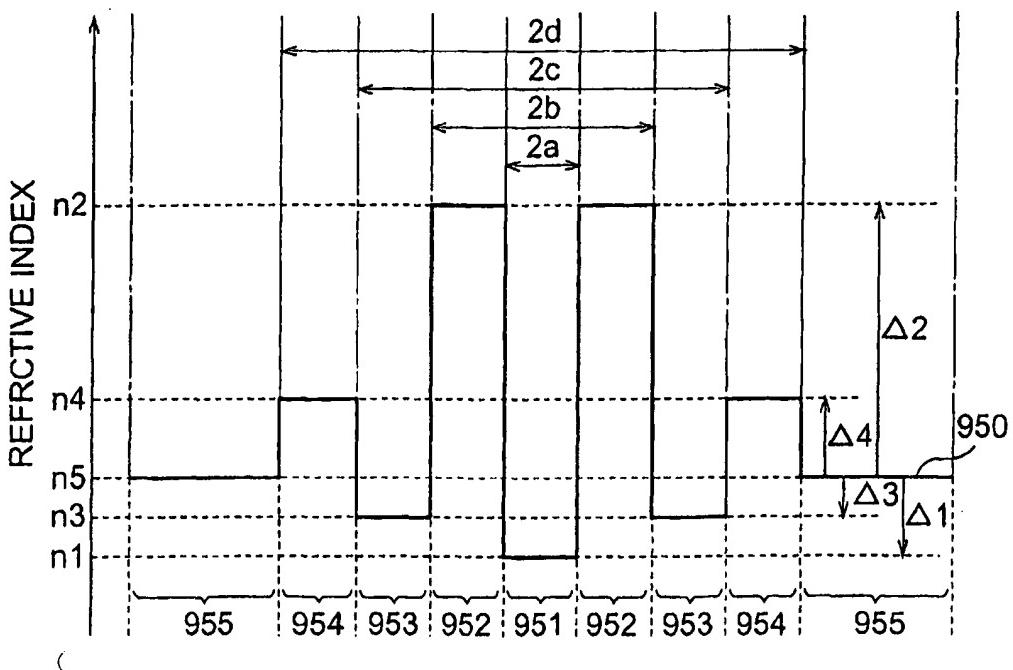
Fig.9***Fig.10***

FIG. 11

	1st Embodi-ment	2nd Embodi-ment	3rd Embodi-ment	4th Embodi-ment	5th Embodi-ment	6th Embodi-ment	7th Embodi-ment	8th Embodi-ment	9th Embodi-ment	10th Embodi-ment	11th Embodi-ment	12th Embodi-ment	13th Embodi-ment
Zero-dispersion wavelength (μm)	1.44	1.46	1.42	1.41	1.48	1.42	1.41	1.42	1.44	1.42	1.42	1.41	1.41
Dispersion slope (ps/nm ² /km) at zero-dispersion wavelength	0.060	0.053	0.079	0.081	0.064	0.056	0.075	0.084	0.077	0.070	0.080	0.088	0.057
Dispersion slope (ps/nm ² /km) at wavelength 1.55 μm	0.054	0.049	0.070	0.070	0.064	0.052	0.061	0.068	0.061	0.058	0.065	0.071	0.048
Cutoff wavelength (μm)	0.96	0.93	1.19	1.15	1.24	1.23	1.10	1.17	1.22	1.18	1.16	1.22	1.04
Dispersion (ps/nm/km) at wavelength 1.20 μm	-18.5	-18.5	-20.8	-20.3	-16.4	-20.1	-22.9	-21.6	-21.5	-21.6	-21.8	-22.5	-15.7
wavelength 1.30 μm	-9.6	-10.1	-10.6	-9.9	-11.9	-7.9	-9.3	-11.1	-10.2	-10.8	-10.5	-10.6	-7.2
wavelength 1.45 μm	0.6	-0.5	2.1	3.1	-1.9	1.6	3.0	2.4	2.2	0.7	2.3	3.4	2.2
wavelength 1.55 μm	6.2	4.3	9.3	10.2	4.8	6.6	9.4	9.9	9.1	7.3	9.5	11.0	7.1
wavelength 1.60 μm	8.8	6.7	12.8	13.7	8.0	9.2	12.4	13.2	12.1	10.1	12.7	14.5	9.4
Bending loss (dB/turn) at wavelength 1.55 μm	0.06	0.20	0.006	0.004	0.0008	0.02	0.3	0.2	0.2	0.03	0.005	0.4	0.04
at diameter 32 mm	49.1	47.2	63.6	62.0	53.9	57.1	67.3	79.1	73.5	59.6	62.6	92.7	52.2
Effective area (μm^2) at wavelength 1.55 μm													

FIG. 12

	14th Embodiment	15th Embodiment	16th Embodiment	17th Embodiment	18th Embodiment	19th Embodiment	20th Embodiment	21st Embodiment	22nd Embodiment
Zero-dispersion wavelength (μm)	1.41	1.46 (1.457)	1.47	1.40	1.41	1.38	1.40	1.40	1.39
Dispersion slope ($\text{ps}/(\text{nm}^2/\text{km})$ at zero-dispersion wavelength	0.065	0.060	0.065	0.071	0.058	0.065	0.059	0.057	0.052
Dispersion slope ($\text{ps}/(\text{nm}^2/\text{km})$ at wavelength $1.55 \mu\text{m}$)	0.055	0.060	0.065	0.059	0.040	0.047	0.043	0.046	0.023
Cutoff wavelength (μm)	1.25	1.07	1.37	1.78	1.75	1.52	1.59	1.44	1.66
Dispersion ($\text{ps}/(\text{nm}/\text{km})$ at wavelength $1.20 \mu\text{m}$)	-18.8	-20.2	-21.1	-17.4	-16.5	-14.5	-15.8	-15.2	-14.4
wavelength $1.30 \mu\text{m}$	-7.7	-11.1	-12.1	-7.7	-7.5	-5.4	-6.9	-6.5	-5.7
wavelength $1.45 \mu\text{m}$	2.5	-0.6	-1.3	3.5	2.1	4.4	2.7	2.7	2.8
wavelength $1.55 \mu\text{m}$	8.5	5.7	5.1	9.7	6.8	9.4	7.4	7.5	5.9
wavelength $1.60 \mu\text{m}$	11.2	8.7	8.4	12.6	8.6	11.7	9.5	9.8	7.0
Bending loss (dB/turn)	0.00002	0.00006	0.02	0.00002	0.2	0.07	0.001	0.1	0.3
at wavelength $1.55 \mu\text{m}$									
at diameter 32mm									
Effective area (μm^2)	50.1	45.3	62.6	60.3	57.1	64.5	50.4	64.4	55.6
at wavelength $1.55 \mu\text{m}$									

Fig.13

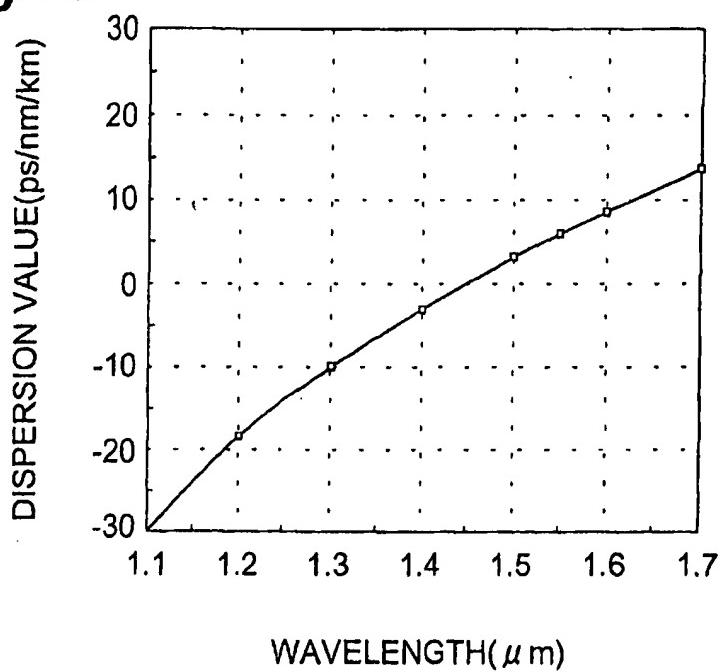


Fig.14

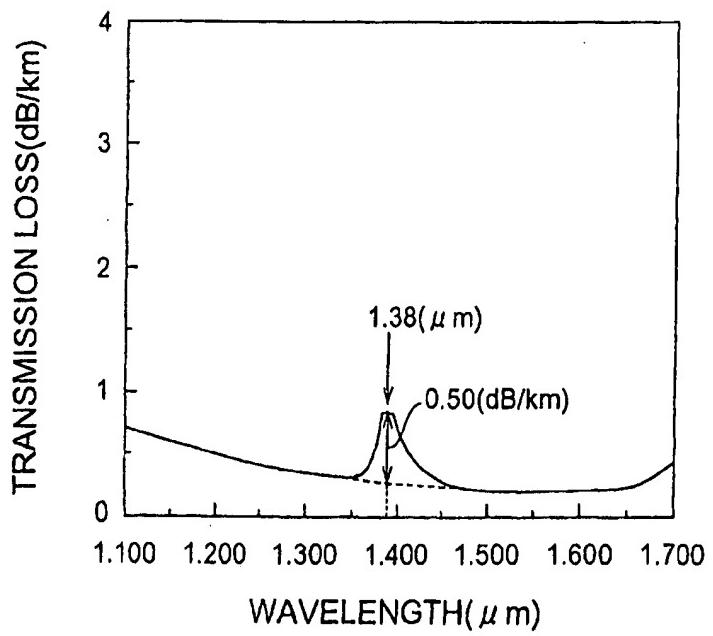


Fig.15

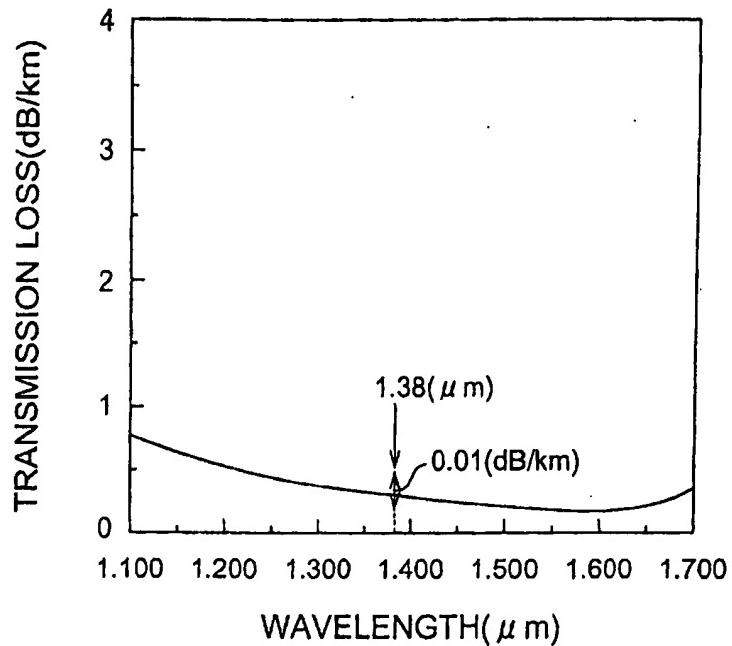


Fig.16

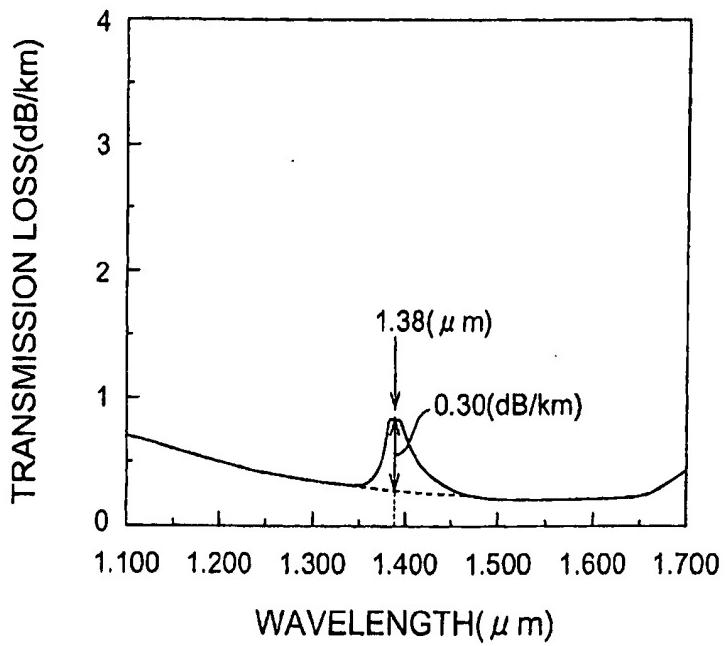


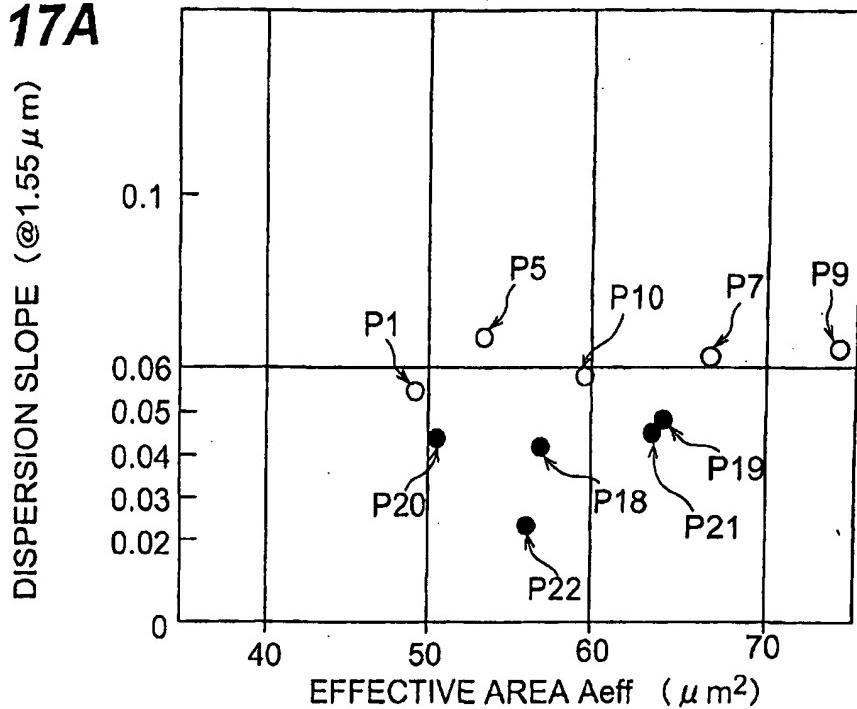
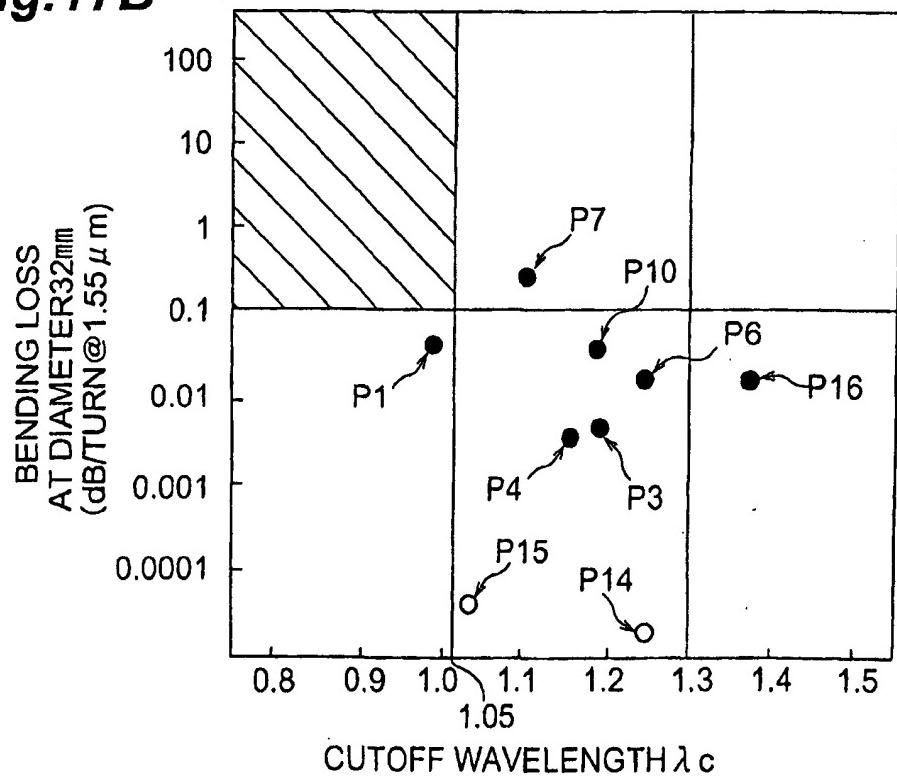
Fig. 17A**Fig. 17B**

Fig. 18A

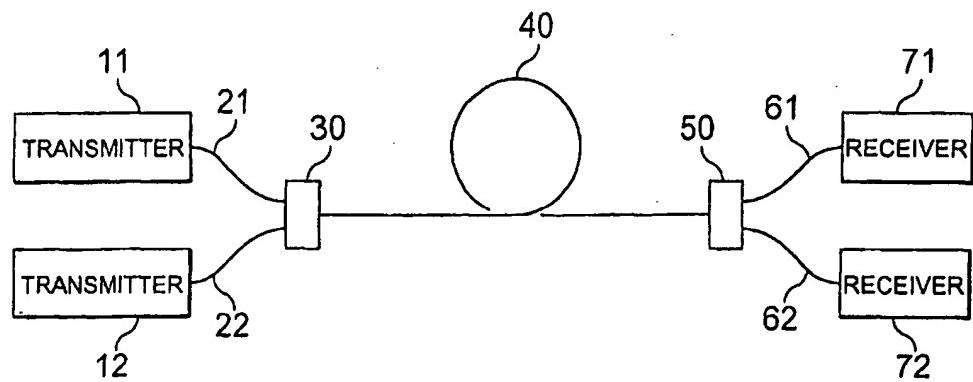
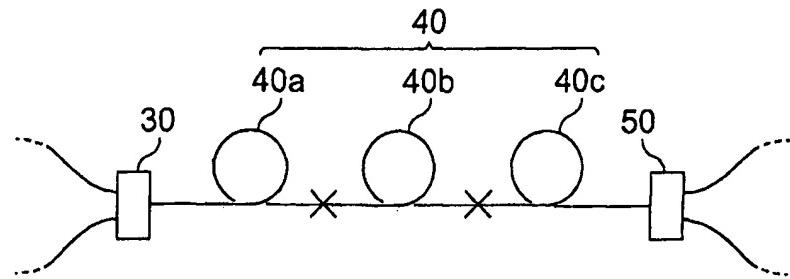


Fig. 18B



INTERNATIONAL SEARCH REPORT		International application No. PCT/JP99/06611
A. CLASSIFICATION OF SUBJECT MATTER Int.Cl' G02B 6/16		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) Int.Cl' G02B 6/00-6/54		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1922-1996 Toroku Jitsuyo Shinan Koho 1994-1999 Kokai Jitsuyo Shinan Koho 1971-1999 Jitsuyo Shinan Toroku Koho 1996-1999		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP, 862069, A2 (NIPPON TELEGRAPH AND TELEPHONE CORPORATION), 15 August, 1997 (15.08.97), Full text; all drawings; especially, column 9; lines 25-53; Figs. 1, 13-15 & JP, 10-300966, A & US, 5963700, A	1,3,6,9-12, 14-16, 19,27 31-33
Y		2,4-5,7-8, 13,17-18, 20-26,28, 29,34-35
A		30
Y	BHAGAVATULA, V.A.; "Dispersion-shifted single-mode fiber for high-bit-rate and multiwavelength systems": OFC '95 Technical Digest, ThH1, pp.259-260., Especially, see Fig. 1, Table 1	4-5,7-8, 17-18,27, 34-35
Y	US, 5732178, A (Sumitomo Electric Industries, Ltd.), 24 March, 1998 (24.03.98), Column 5; lines 45 to 61; Figs. 1, 10 & JP, 9-211249, A	9-10,21,33
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 18 February, 2000 (18.02.00)	Date of mailing of the international search report 07 March, 2000 (07.03.00)	
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer	
Facsimile No.	Telephone No.	

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT		International application No. PCT/JP99/06611
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, 5822488, A (Sumitomo Electric Industries, Ltd.), 13 October, 1998 (13.10.98) & JP, 9-159856, A	9-10, 20-29, 33
Y	EP, 851245, A2 (Sumitomo Electric Industries, Ltd.), 01 July, 1998 (01.07.98) & JP, 10-239550, A & CA, 2225889, A & TW, 356531, A & KR, 98064539, A	9-10, 20-29, 33
Y	EP, 656326, A2 (AT&T Corp.), 07 June, 1995 (07.06.95) & JP, 7-206462, A & US, 5397372, A & CA, 2118351, A & DE, 69413181, E	13
Y	JP, 10-53429, A (Sumitomo Electric Industries, Ltd.), 24 February, 1998 (24.02.98) (Family: none)	13
A	EP, 604787, A1 (Corning Inc.), 06 July, 1994 (06.07.94) & JP, 6-235839, A & AU, 5262993, A	17-18, 34-35
A	Masayuki Nishimura, "Multiwavelength Optical Fiber"; O plus E, Vol.19, No.11 (series No.216), November, 1997, (Japan), Shin Gijutsu Communications issue, pp.143-148 especially, page 146, Fig.2	21-29
P,A	EP, 887670, A2 (LUCENT TECHNOLOGIES INC.), 30 December, 1998 (30.12.98) & AU, 9871965, A & CA, 2240220, A & JP, 11-1171575, A & CN, 1221709, A	13

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP99/06611

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.: because they relate to subject matter not required to be searched by this Authority, namely:

2. Claims Nos.: because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

The common matters of the inventions of claims 1 to 35 are the matters of claim 1, and the matters of invention of claim 1 are disclosed in EP, 862069, A2 (NIPPON TELEGRAPH AND TELEPHONE CORPORATION), 15 August, 1997 (15. 08. 97), lines 29-37, column 9, and Fig.14, and do not make any contribution over the prior art.

Therefore, the common matters cannot be the "special technical features" described in the second sentence of PCT Rule 13.2. Hence the inventions of claims 1 to 34 do not meet the requirement of unity of invention.

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest The additional search fees were accompanied by the applicant's protest.
 No protest accompanied the payment of additional search fees.